

THE ESK HEAD MÉLANGE IN
THE ESK HEAD/OKUKU AREA,
NORTH CANTERBURY

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ABSTRACT

The Esk Head Mélange is a zone of chaotically mixed rocks roughly 12 km wide, trending for at least 60 km north-northwest across North Canterbury. It is characterized on all scales by a "block and matrix" structure and consists of blocks of sandstone/mudstone, conglomerate, metavolcanics, chert and limestone within a dark muddy matrix. The zone demonstrates gradational boundaries with Torlesse subterrane to the southwest and northeast.

Within the Esk Head/Okuku study area, the mélange is a structurally coherent zone, steeply overturned to the southwest, with a systematic fabric dominated by pervasive shearing and modified by latter flattening. The zone has acted as a structural marker which records post mélange Mesozoic deformation dominated by steeply plunging, gentle to open flexures and sinistral faults.

Fragmentation within the mélange was accomplished by boudinage and shear-related processes. Several families of minor folds are directly related to shearing and asymmetric folding suggests a southwest over northeast sense of movement. Early faulting and related shear fractures readjust the mélange and result in further mixing. Low grade metamorphism, i.e. zeolite facies, was ongoing during deformation throughout the zone and margins.

Sandstone/mudstone sequences within the mélange represent highly dismembered elements of original submarine fans. Volcanics, cherts, and limestones comprise a "volcanogenic" association and represent scraps of an original basement. The mélange also incorporates "olistostromal components" up to 1 km in thickness, dismembered to varying degrees and

directly related to mélangé formation.

The Esk Head Mélangé is regarded as a tectonic mélangé created in the upper levels of a shallow westward dipping subduction zone during the Early Cretaceous and possibly Jurassic. Emplacement of the zone may be related to accretionary underplating. However a model of near vertical emplacement by subduction-driven upward movement on the landward margin of the active accretionary wedge is considered more likely.

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CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION AND AIMS

The Esk Head Mélange (Bradshaw, 1973) is a zone of chaotically mixed rocks, roughly 12 km wide, trending north-northwest across North Canterbury. The zone has been traced for over 60 kilometres and reconnaissance mapping suggests its continuation into the Leatham River area (J.D. Bradshaw, pers.comm., M.R. Johnston, pers.comm.) (figure 1.1). It is characterized on all scales by a block and matrix texture, and includes blocks and bedded elements of sandstone/mudstone and conglomerate and blocks of volcanics, limestone and chert, all occurring generally within a dark muddy matrix.

This study represents a detailed examination of the Esk Head Mélange within selected areas of North Canterbury. The aims of the project are: 1) to produce a detailed geologic map of the zone and its immediate boundaries within these areas; 2) to suggest possible mechanisms for the formation of the mélange and to discuss their regional geologic implications. Two main transects across the zone were chosen on the basis of relative continuity of stream sections and ease of access (figure 1.2. location map). The northern transect (Esk Head study area) embodies mapping along the North Esk River and South Branch of the Hurunui River and several major tributaries of these. The southern transect (Okuku study area) includes mapping along the Ashley and Okuku rivers, Middle and South Branches of the Waipara River and several tributaries of all of these. Stream sections provide a relatively continuous band of exposure in an area otherwise dominated by hilly grassland with only scattered outcrop.

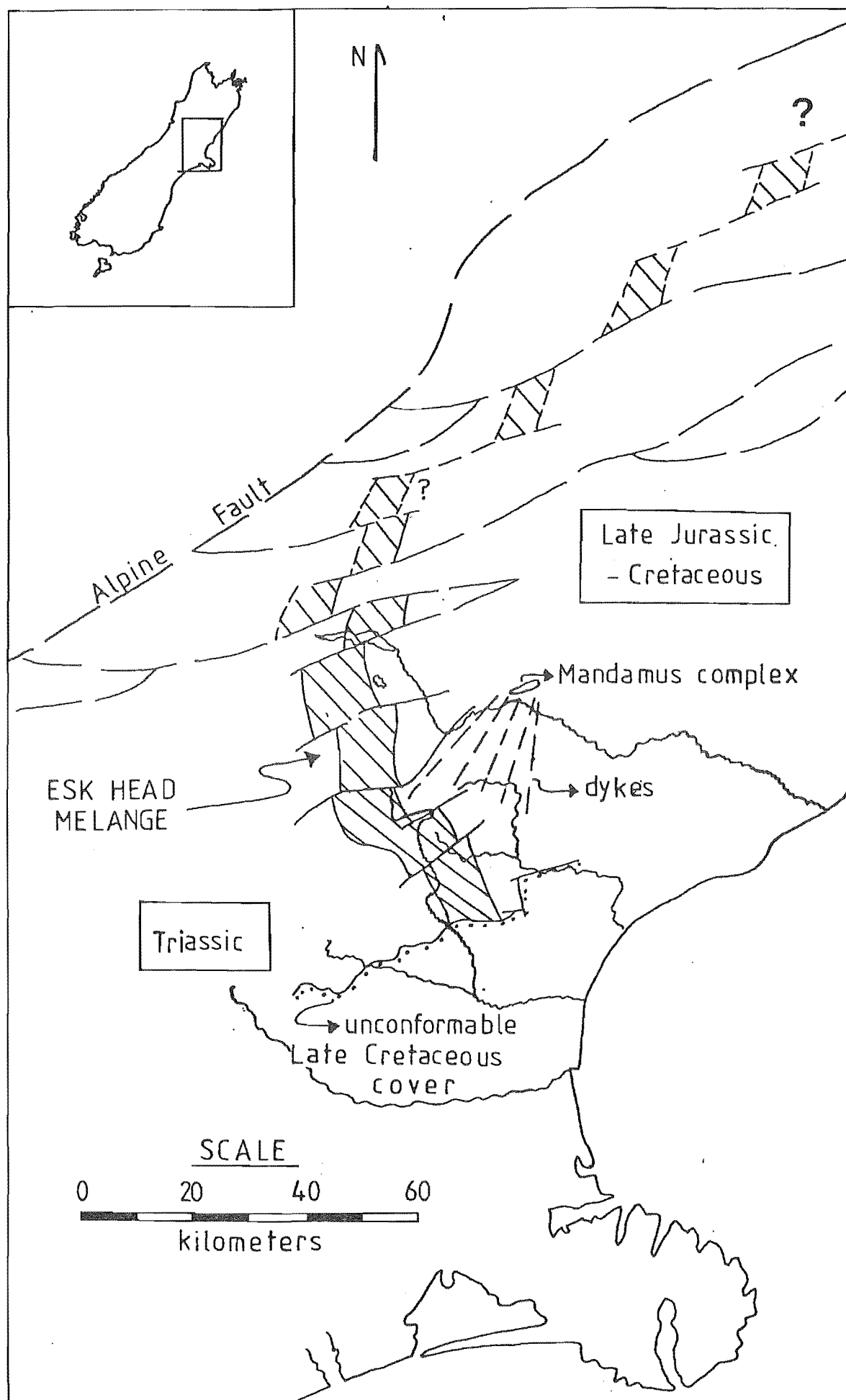
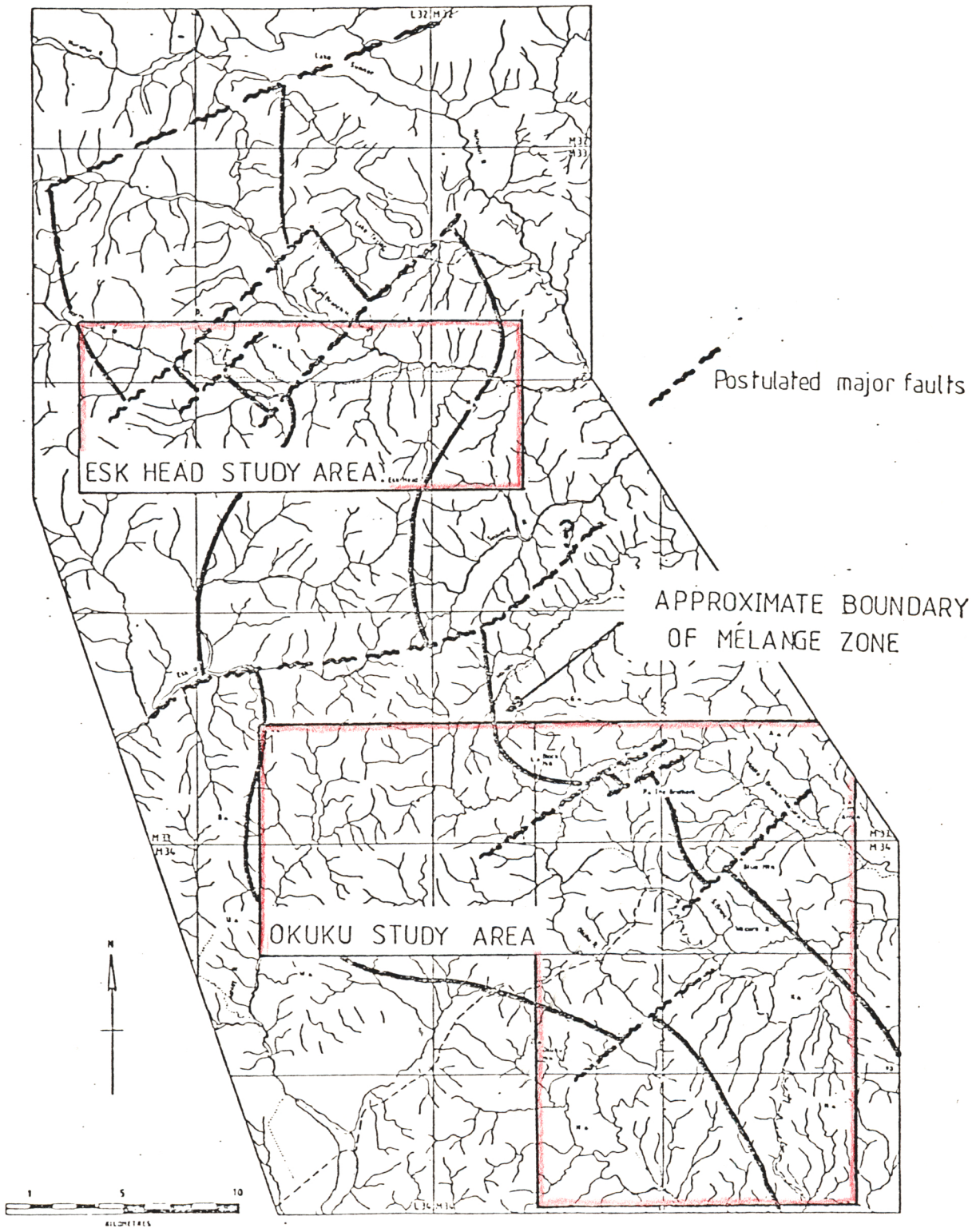


Figure 1.1: Location of the Esk Head Mélange.



1.2 TOPOGRAPHY AND VEGETATION

Relief in the Esk Head study area ranges from 1864 m (Esk Head) to an average of 640 m in the valley bottom. The Okuku area ranges from 1440 m (Mt. Gordon) to an average river valley elevation of 545 m.

The areas are dominated by tussock grassland with isolated stands of beech forest. This forest cover becomes more extensive in the upper reaches of the North Esk River and its tributary Lucy Stream and in the upper reaches of the Ashley River (Puketeraki State Forest). Grass cover changes to subalpine varieties on the higher ridges and thins to reveal scattered outcrop, partially covered by localized scree, on some ridges and peaks.

1.3 ACCESS

Access to the Esk Head area is provided by a metalled road to Esk Head Station, a well maintained track beyond to Deep Stream hut, and four-wheel-drive tracks further (to Bush Camp Hut). A walking track continues along the North Esk River to the North Esk hut.

Primary access to the Okuku area is provided by the Okuku Pass/Lees Valley metalled road. Four-wheel-drive tracks extend from The Brother's homestead (M34/592 985) to allow access to the northeast part of this study area. Alternative access is from the east via McDonald Downs station or from the north via Melrose station or the Waitohi River track. The upper Ashley River area is reached by four-wheel-drive and walking track, along the river northward from the Lees Valley road. Access to the southern part of the study area is provided by a metalled road and track which continues to the vicinity of Round Hill (M34/590 860).

1.4 REVIEW OF PREVIOUS WORK

Alexander McKay mentioned the occurrence of fossiliferous Triassic limestones in the Okuku Range in 1877. He revisited the area of the Ashley and Okuku Rivers in 1881 and was one of the first to note the association of "diabasic ash", limestone and chert. However, referring apparently to the upper Ashley River area, McKay was prompted to write "... it would be rash to pronounce definitely upon the sequence of the different rocks seen in this section, as the whole strata are so contorted and disturbed that, except a general dip to the northwest is observable, the section is obscure and a difficult one".

Mason (1941) briefly discusses the Torlesse basement in the Mt. Grey area. He describes the most common rock type as coarse grey feldspathic sandstone with interbeds of argillite and rare bands of "red jasperoid material". He also provides a description of *mélange* material: "Conglomerates [sic] in the east branch of the Grey (river) are an unusual type : they are coarse and unsorted, containing poorly rounded rock fragments up to one foot in greatest length. These rock fragments consist mainly of grey sandstone, but there is also a considerable amount of light-grey finely crystalline limestone. The place of origin of these limestone fragments is unknown and their age could not be determined as no fossils were found in them".

An Msc. mapping project completed by G. Warren in 1955 extended over a large part of the present Okuku study area. Warren found many of the important fossil localities of the area, and rediscovered the *Monotis*-bearing limestones near Lees Pass, first mentioned by McKay (see Campbell and Warren, 1955). Warren also noted the presence of trachytic dykes in the area and tentatively correlated them with the

emplacement of the Mandamus syenite complex to the northeast (figure 1.1).

The fossil localities of Warren were incorporated into a wider survey of Torlesse fossil localities (Campbell and Warren, 1965). The authors pointed out the presence of Late Triassic *Terebellina* and *Monotis* in the reasonably coherent sequence exposed along the Ashley River southwest of Lees Valley. The juxtaposition, in the Okuku River area, of Late Triassic *Monotis* localities and Late Jurassic *Belemnopsis* and *Inoceramus* localities was indicated. The *Monotis*-bearing limestones of the Esk Head area were also listed.

In the area immediately to the east, Bradshaw (1972) recognized the presence of tectonic slides marked by autoclastic breccia and apparently associated with steeply plunging megascopic folds. These result in Upper Triassic rocks structurally overlying Upper Jurassic. He suggested a gravity tectonic origin for the slides with subsequent rotation of the rocks into roughly vertical attitudes.

In the following year, Bradshaw (1973) proposed the name Esk Head M \acute{e} lange for a belt of chaotically mixed rocks which he traced northwest across North Canterbury in the valleys of the Ashley, Okuku, Grey, Waipara and Hurunui Rivers. The allochthonous nature of Upper Triassic fossiliferous limestone blocks was stressed and he suggested a post Upper Jurassic age of m \acute{e} lange formation based on the presence of Upper Jurassic fossil localities with the m \acute{e} lange belt. An upper age limit is suggested by the undeformed crosscutting lamprophyric dykes of early Upper Cretaceous age which had earlier been described by G. Warren. Furthermore, undisturbed Upper Cretaceous sediments overlie the southern projection of the m \acute{e} lange. This relationship is observed, for example, in the Grey River (Mason, 1941).

Bradshaw pointed out the similarity between the deformational style observed in the *mélange* and that of the tectonic slides mapped to the northeast and noted the gradational boundaries of the *mélange*. He also observed that the low grade metamorphism of the area appeared to postdate *mélange* formation and regarded the Esk Head as a tectonic *mélange*.

The western boundary of the *mélange* zone was mapped by Petrie (1974) within the Studleigh Range, North Canterbury. The chaotically mixed zone is mapped as passing transitionally westward through disrupted strata into bedded sediments of the Torlesse. Petrie believed the zone to be a tectonic *mélange* related to gravity sliding.

Bradshaw (1979) considered the Esk Head *Mélange*, plus the external zones of tectonic slides, to be a subterrane within the Torlesse terrane. He regarded it as a complex tectonic contact between the Late Carboniferous to Late Triassic Rakaia subterrane to the southwest and the Late Jurassic to Early Cretaceous Pahau subterrane to the northeast. This view was expanded in a review of the Rangitata orogeny (Bradshaw, Andrews and Adams, 1980). The refined boundaries of the *mélange* zone (Bradshaw, 1980) are adopted here with minor modifications.

Recent regional scale studies of the Torlesse (Pringle, 1980; Mackinnon, 1980, in press) have adopted the perspective of Bradshaw *et al.*, (1980) with regard to the nature and significance of the Esk Head *Mélange* as a complex tectonic contact within the Torlesse.

1.5 TERMINOLOGY

Mélange

The term *mélange* has received varied usage in the geologic literature of the past decade. A non-genetic use of the term is applied in many recent publications (Swarbrick and Naylor, 1980; Bosworth and Vollmer, 1981; Page and Suppe, 1981; and others). The 1980 Penrose Conference (Silver and Beutner, 1980) defines a *mélange* as "a mappable, internally fragmented and mixed rock body containing a variety of blocks, commonly in a pervasively deformed matrix". This definition is adopted in this thesis.

Olistostrome

The term olistostrome is used here as a descriptive term. It refers to highly mixed rock bodies which are interpreted as resulting from any combination of submarine sliding and other related gravity-induced processes (Flores, 1955; Abbate et al., 1970; Hoedemaeker, 1973). These include sliding, slumping and debris flow.

Matrix

Because the *mélange* displays a block and matrix texture on all scales and includes "blocks" from mm-sized grains to metre-sized blocks to huge rafts up to roughly .5 x 1.5 km, the distinction of a *matrix* becomes arbitrary. In this thesis *matrix* is used in two ways:

- 1) In the conventional sense of sedimentary geology; that is to mean the smaller-size population of a clastic sedimentary deposit which generally occurs interstitially to a larger-size population, frequently in such a high percentage as to enclose and support the larger population. For example, a medium sand matrix (smaller-size population) with a boulder conglomerate (larger-size population).

2) With regard specifically to the *mélange*, *matrix* refers strictly to the dark mudstone dominated material which is weakly to strongly cleaved and which contains blocks of other lithologies.

Distinctive lithologies consisting of mudstone plus blocks have been recognized in this study (e.g. blocky/laminar association - chapter 3). These act in part as a matrix to larger rafts but are referred to herein as *matrix associations* to distinguish them from the above.

Notes on Maps

Maps provided with this study are at scales of 1:15,000 and 1:63,360. Topographic contours on the 1:15,000 sheets are in feet. One sheet is provided for the North Esk study area and three sheets for the Okuku study area (see location map 2). All grid references quoted for outcrops, sections, fossil localities, etc. are based on the 1975 metric grid. Established fossil localities are referred to by their New Zealand Fossil Record File numbers, e.g. S60/f563.

CHAPTER TWO

PRIMARY ROCK TYPES

2.1 INTRODUCTION

The discussion of rock types mapped in this study is divided into two chapters. Chapter 2 provides a description and discussion of primary rock types, similar to those described from other areas of the Torlesse (e.g. Andrews et al., 1976; Pringle, 1980; Hicks, 1981). Chapter 3 deals with rock types characteristic of the Esk Head Mélange. While conglomerates have been described from other studies of the Torlesse, the "polymict conglomerate association" of this study is believed to be genetically related to mélange formation and is included in chapter 3.

Because of the nature of exposure in the area, and the commonly fractured, disrupted and apparently dislocated nature of the rocks, the geometry of units and their original relationships are difficult or impossible to determine. For this reason, the practice of Bradshaw (1972) in describing lithologic "associations" rather than facies or lithotypes, is adopted in this study.

Primary rock types are discussed below under the broad headings of 1) Sandstone and sandstone/mudstone associations, 2) Volcanogenic associations, 3) Younger rocks.

2.1.1 Degree of Disruption

The field geologist working in this area is confronted with rocks which have been disrupted to a varying degree. Sandstone sections may range from well-bedded, virtually intact sequences through moderately










disrupted units which have been sheared or fractured, to units which appear only as chaotically fractured sandstone, with minor mudstone, and give little clue as to original bedding. A three stage "scale" was used in the field as a simple descriptive tool to record this degree of disruption. It is a crude measure of the disruption of bedding and so is obviously applicable to the bedded associations described in section 2 below (figure 2.1). The scale is this:

- 1) "intact bedding" - Beds may have suffered minor interbed shearing or may display minor fracturing with little offset (less than 5 cm). Otherwise the original bedding characteristics are clear although sole markings are rarely observed.
- 2) "moderate disruption" - Bed thickness and sandstone/mudstone ratios can be estimated but beds have usually suffered interbed movement and related low angle conjugate shearing. This frequently results in an "elongate lozenge" structure. Bedding may also be disrupted by brittle fracture and minor faulting. A vague fracture cleavage may become most apparent in thick bedded units. Younging direction generally cannot be determined.
- 3) "highly disrupted" - Only rarely is bedding of any type apparent at this level of disruption. Original bed thicknesses can frequently be only guessed and usually only a vague shear fabric can be obtained in terms of attitude. Exposure is dominated by highly fractured and sheared sandstone and original units are often believed to be thick bedded sandstone.

Figure 2.1 illustrates the three levels of disruption with respect to thick, medium and thin bedded units. The scale is purely descriptive. No equivatence of strain is implied across lithologic association boundaries. For example, "moderate disruption" in medium bedded sandstone does not necessarily record the same strain as moderate disruption in

FIGURE 2-1. DISRUPTION "SCALE"

INCREASING
DISRUPTION

<p>12 LITHOLOGIC ASSOCIATION</p> <p>▲</p>	<p>THIN BEDED ASSOCIATION</p>	<p>MEDIUM BEDED ASSOCIATION</p>	<p>THICK BEDED ASSOCIATION</p>
<p>"INTACT BEDDING"</p>			
<p>"MODERATELY DISRUPTED"</p>			
<p>"HIGHLY DISRUPTED"</p>			

thick bedded sandstone. This approach is used in an attempt to map original lithologic associations and record the degree to which these have been disrupted.

Specific problems with this approach should be noted:

- 1) Thin bedded sandstone may be tectonically shredded along subtle partings or amalgamation surfaces and appear as medium bedded units in disrupted sequences. Close examination of "bed" margins in the field has minimized error of this kind but it cannot be discounted.
- 2) Within thin bedded sandstone/mudstone sequences, the transition from intact units to "broken formation" appears to be an abrupt one. The distinction between broken formation and blocky/laminar mélange matrix is somewhat arbitrary. Broken formation, however, is generally regarded as a mudstone-rich, highly disrupted, thin or locally medium bedded sandstone/mudstone sequence where some measure of stratal continuity can still be discerned (figure 2.1). Some blocky/laminar mélange matrix may be derived from continued disruption of broken formation (see sections 3.3 and 5.5).

The results of using this approach will be included in a discussion of fabric in chapter 5 - Structure.

2.2 SANDSTONE AND SANDSTONE/MUDSTONE ASSOCIATIONS

Alternating sandstone/mudstone sequences have been divided into lithologic associations based largely on bed thickness. These are intended to represent naturally occurring divisions.

2.2.1 Thick bedded association

The thick bedded association comprises sandstone dominated

sequences, with sandstones generally 1 to 3 metres thick and with common dark mudstone interbeds. Two subassociations have been observed but not mapped. In the first case, beds are generally about 1 metre thick and commonly exhibit mudstone interbeds from 5 to 15 cm in thickness. In the second case, sandstone beds are generally thicker, roughly 3 metres in thickness and are separated by units, up to 2 metres thick, of laminated siltstone to very fine sandstone. These locally contain fine sandstone beds up to 10 cm in thickness (figure 2.2). The geometry of beds in this association is unknown.

The sandstone beds of this association are generally medium sandstone. They are frequently quartz rich but contain highly variable percentages (0 to 30%) of rock fragments which are generally dark mudstone. These range from coarse sand to pebble size. Particularly where rock fragments are abundant, grading is commonly observed. Crossbedding or ripple structures have not been seen. Basal contacts of beds are generally sharp. Sole marks are very rare and have been observed in place at only three localities. All of these are outside the western margin of the *mélange* zone. The first is situated above Lucy Stream on the southern flank of Mt. Crossley (L33/364 174). Here load casting features surround and modify larger apparent flute casts on the base of beds roughly 2 metres in thickness (figure 2.3). On the Ashley River at L34/425 945, flute casts are exposed on the base of a 1.5 metre sandstone bed. They have a present azimuth and plunge of $325^{\circ}/26^{\circ}\text{NW}$. Further south on the Ashley, in a well preserved section at L34/423 925, elongate tool marks on the base of a 3 metre bed are presently oriented at $331^{\circ}/09^{\circ}\text{NW}$ (azimuth/plunge). The paucity of transport directions does not warrant a long discussion here of the problem of restoration of bedding to original orientation. If beds are simply rotated to the horizontal about strike, transport directions towards 275° and 320° (140°)

THICK BEDDED ASSOCIATION

NORTH ESK RIVER

(L33/452 204)

(PACED)

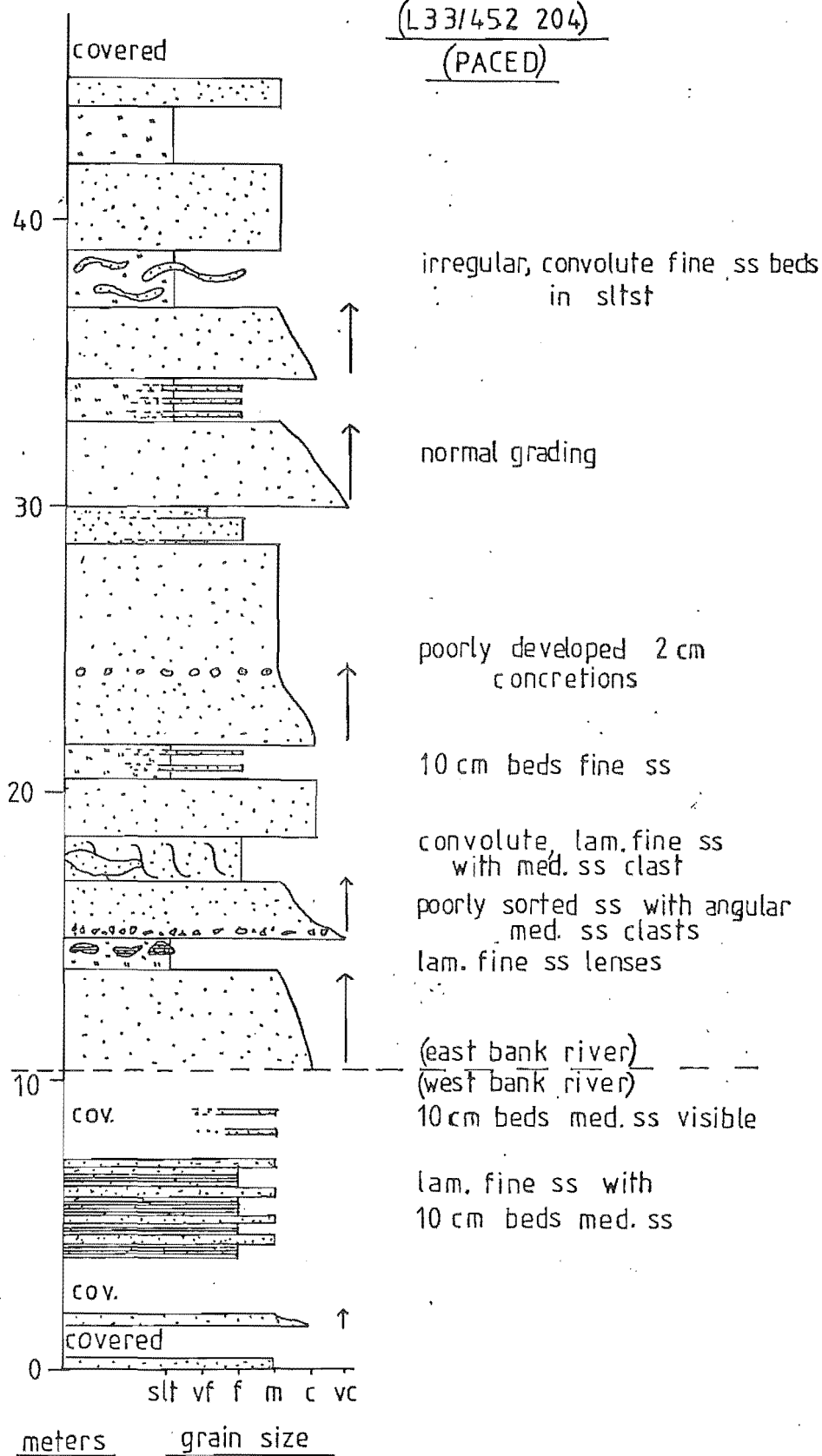


Figure 2.2: Measured section : thick bedded association.

are suggested. However, the rotation history of bedding on the southwest margin of the mélangé zone cannot be determined.

Amalgamation surfaces:

Many of the thicker beds (3 m or thicker) display irregular internal surfaces which suggest that the beds may be composites of several thinner sandstone units. These surfaces range from clear scours accompanied by basal pebbles or granules to subtle planes marked only by a moderate grain size difference (figure 2.4). The latter are regarded as amalgamation surfaces. They frequently define units 15 to 20 cm in thickness. I suspect that in some cases these surfaces may be tectonically exploited, especially in early stages of lithification, to produce an "elongate lozenge" shear structure. Figure 2.5 illustrates an early development of this in a thick bedded unit.

2.2.2 Massive sandstone association

This remarkably uniform association consists of grey, massive, medium sandstone in units ranging from 10 m up to 30 m in apparent thickness. No well-exposed upper or lower contacts have been observed. The sandstone is generally very well indurated and quartz rich. It shows a uniform grain size over its entire thickness.

These units locally show vague vertical sheet structures (Laird, 1970). On highly weathered, water washed surfaces (usually fallen blocks), irregular pelitic partings may be seen, and are believed to be roughly parallel to bedding (figure 2.6). These locally take on the aspect of flattened dish structures.

Part of a thick exposure of the massive sandstone association in the South Branch Waipara River (M34/651 956) displays a disrupted, pillowed

Figure 2.3: Sole marks on the base of a 2 metre bed.
(Mt. Crossley area)

Figure 2.4: Subtle amalgamation surface (arrows) within
thick sandstone bed.

Figure 2.5: Possible early stage tectonic exploitation of
amalgamation surfaces in thick bedded sandstone.



2.4



2.5

structure (figure 2.7). Here lozenges or pillows of sandstone approximately .4 m x 2 m are chaotically oriented and locally pinch minor amounts of mudstone between them. Deformation was evidently highly ductile, and may be related to early downslope movement of poorly lithified sandstone.

This massive sandstone lithology is characteristically associated with the thick bedded association. Where it is exposed on the lower Okuku River (M34/576 860) map relationships suggest that the massive sandstone association occurs as lenses, possibly channels, within thick bedded units.

2.2.3 Medium bedded association

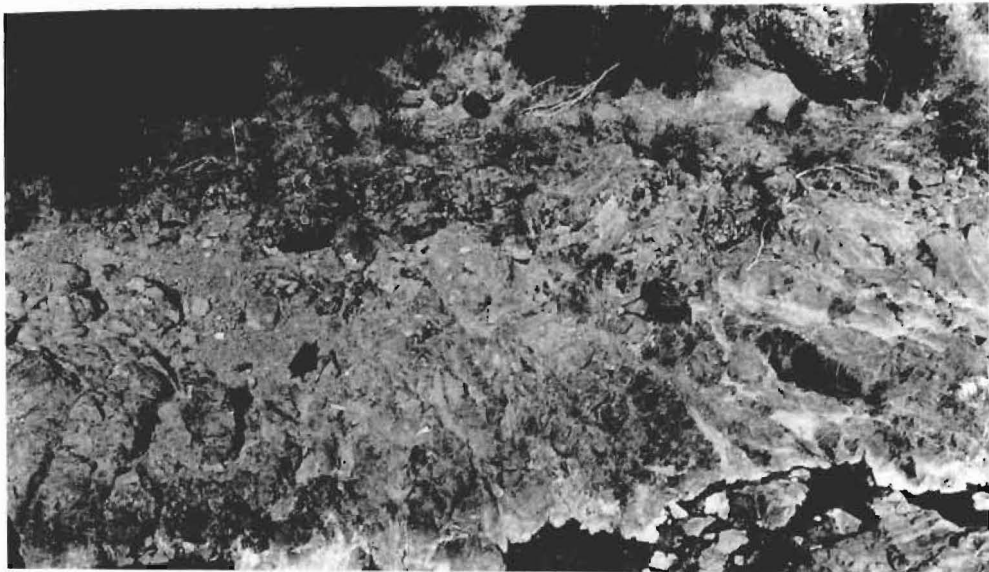
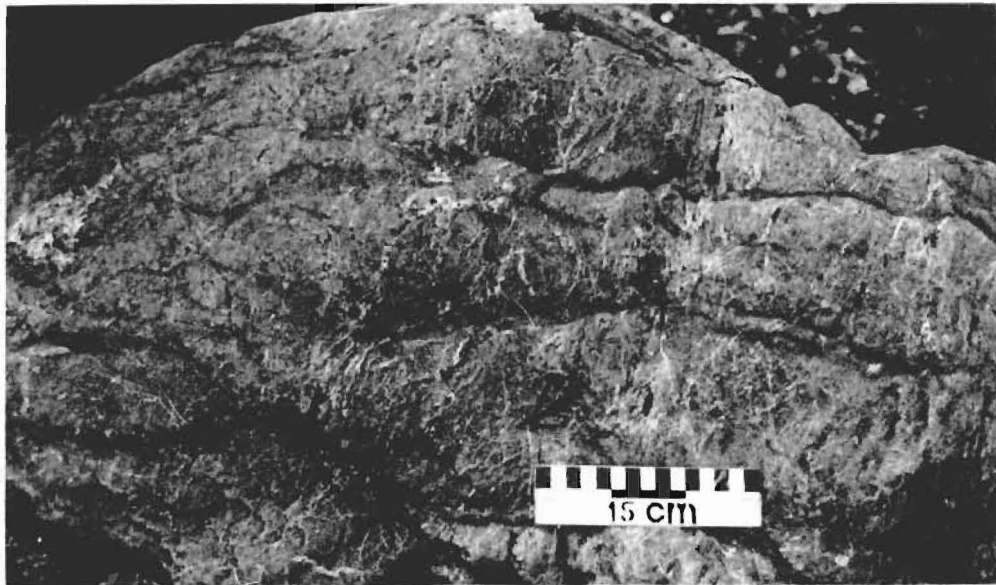
The medium bedded association is defined by a bed thickness ranging from 20 cm to 1 m. Sandstone beds are commonly approximately 40 cm. thick. They display very few internal structures. Laminations of 1 mm scale are visible locally. These are generally parallel laminations, with very sparse suggestions of ripple laminations. Grading is rarely observed. Sandstone beds commonly display sharp bases and sharp tops. Sandstone/mudstone ratios are variable but generally in the range 2:1 to 4:1. They are frequently difficult to estimate because of the interbed shearing which these rocks have suffered. Commonly, beds display thin interbeds of mudstone (<5 cm) and here have sandstone/mudstone ratios of approximately 4:1. Figure 2.8 illustrates the more rare case where the sandstone/mudstone ratio becomes approximately 1:2.

Bedding geometry within this association is uncertain. Medium bedded units pass transitionally into both thin bedded units and thick bedded units. They are also seen to be interbedded with each on a scale of 20 m.

Figure 2.6: Irregular, horizontal pelitic partings within massive sandstone association

Figure 2.7: Disrupted, "pillowed" massive sandstone (arrow indicates hammer for scale)

Figure 2.8: Medium bedded sandstone association with abundant mudstone (backpack for scale)



2.2.4 Thin bedded association (plus mudstone)

Thin bedded units may range from 2 to 20 cm in thickness, but are commonly 5 to 10 cm thick (figure 2.9). Beds are composed of siltstone to very fine sandstone with interbedded dark mudstone. Grading may be locally evident as a colour change from tan coloured siltstone into darker mudstone. The sandstone/mudstone ratio is commonly approximately 1.5:1 but ranges from roughly 2.5:1 to 1:1. Units with higher percentages of mudstone seem particularly subject to deformational effects and are generally noted as broken formation. Undeformed sequences of the thin bedded lithology are relatively rare. Examples are well exposed, however, in an unnamed tributary of the Okuku River north of Stockyard Stream (M33/548 012) (figure 2.10) and on the west flank of Block Hill (M33/550 032).

Massive mudstone units within bedded sequences are relatively rare. Mudstone-dominated packets up to 5 m thick occur within thin bedded sequences in the Esk Head study area, for example in the North Esk River at L33/464 207 and in Deep Stream at L33/451 195. Dark mudstone, hackly in appearance, appears to dominate 30 to 40 m of succession in Stockyard Stream (M33/533 002).

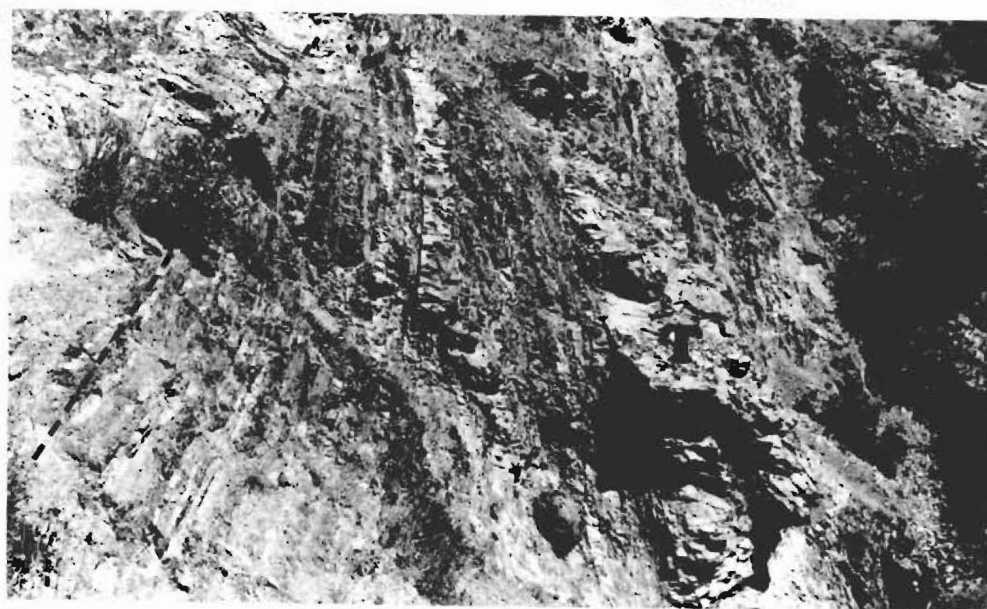
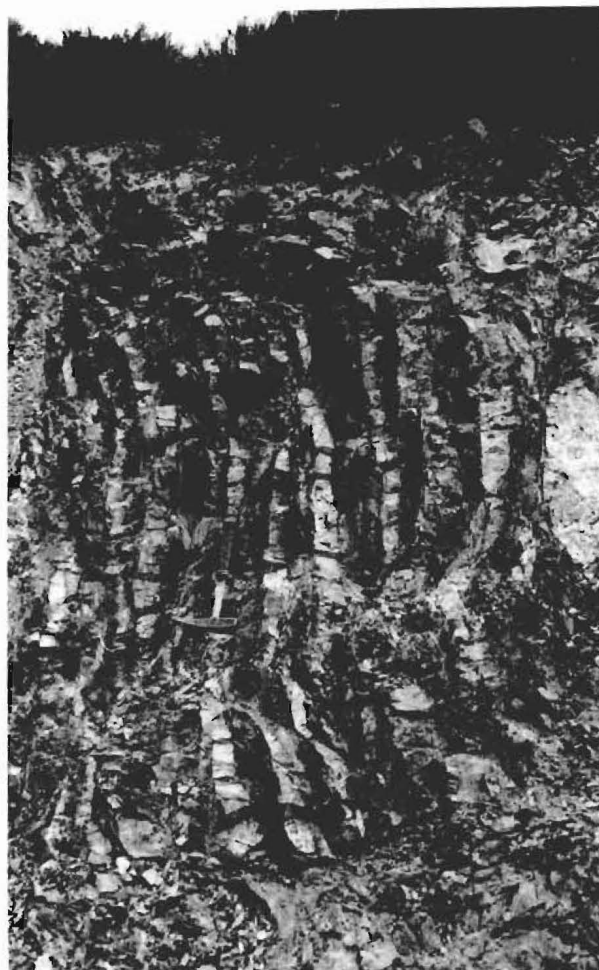
2.2.5 Calcareous Conglomerate

A unique lithology is noted in place at one locality only, in the lower Okuku River at M34/581 871. This is outside the western margin of the Esk Head mélangé and appears to be disrupted only by later stage fracturing or minor faulting.

The lithology is a pebble to boulder conglomerate dominated by tan-weathering, rounded to subangular, spherical to discoid calcareous clasts in a calcareous fine sand matrix. Accessory components include

Figure 2.9: Undisrupted thin bedded association

Figure 2.10: Sequence dominated by thin bedded sandstone/
mudstone "T" indicates isolated thick sandstone
bed. Dashed line indicates "detachment surface"
subparallel to bedding discussed in chapter 5
(pack approximately 35 cm wide)



dark mudstone, carbonaceous material and abundant pyrite. The conglomerate displays a vague platy fabric. No imbrication is noted. The conglomerate occurs in one major bed roughly 5 m in thickness and the succession includes at least two thinner lenses of conglomerate above the major unit. These lenses are a maximum of 40 to 50 cm in thickness. They commonly display 10 to 15 cm of dark mudstone at their base, and have irregular upper surfaces and definite "welded" upper contacts with the dark, laminated medium sandstone which overlies them (figure 2.11). One lens is observed to pinch out from 40 cm to zero thickness over a distance of 2 m. The overall section is shown in figure 2.12. The thick conglomerate bed displays evidence of reverse grading. Rounded boulders, of similar appearance to the underlying mudstone, project from the top of the bed.

In thin section, clasts constitute roughly 45% of the total rock and are dominantly composed of micritic calcite. Textually these include intramicrite, with sparse silt size detrital grains, and dismicrite. Also present are clasts of a very coarse sandstone to granule conglomerate of similar composition to the whole rock. Minor clasts of dark mudstone are generally squeezed around other clasts. All of these clasts are contained within a matrix of sandy microspar. The sand fraction comprises approximately 25 to 30% of the rock. Compositionally it is dominated by quartz but includes feldspar and volcanic rock fragments. The rock also includes shell fragments, angular siltstone granules and abundant framboidal pyrite. All of the above components are surrounded by microspar which represents roughly 30% of the rock.

The main body of conglomerate displays rounded highly discoid clasts which appear to have been derived from individual bedded units of micrite: possibly ripped up, rounded and redeposited. This conglomerate

CALCAREOUS CONGLOMERATE SECTION

OKUKU RIVER (M34/581 871)

(PACED)

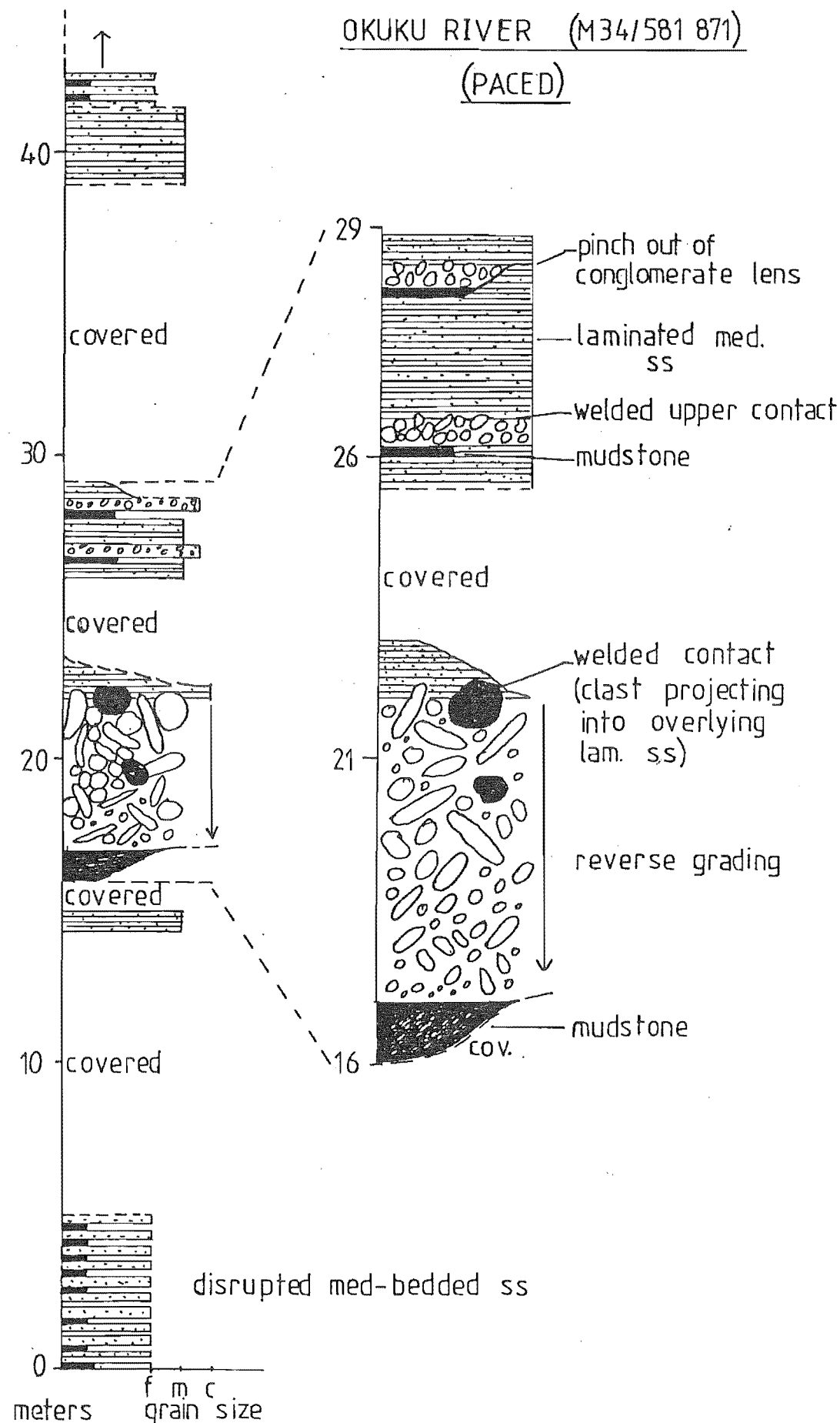


Figure 2.12: Measured section: calcareous conglomerate.

appears to be a debris flow deposit, based on the reverse grading and projection of clasts into overlying sediment. The lensoid, broadly channelized geometry and welded upper contacts are not inconsistent with deposition by debris flow. The presence of carbonaceous material and abundant rounded clasts suggests that some of the components may have been derived from a relatively shallow water source. While not identical with polymict conglomerates described in chapter 3, this conglomerate may represent a less disrupted analogue of the debris flow origin postulated for the polymict conglomerates of the *mélange* zone.

The calcareous conglomerate lithology has been noted in float in two other locations. The first is downstream from the above section (M34/576 865) and may be derived from it. The other float occurrence is of a virtually identical lithology, found in abundance in the South Branch Waipara River at M34/622 961. No exposures were located in place.

2.2.6 Larger order lithologic associations

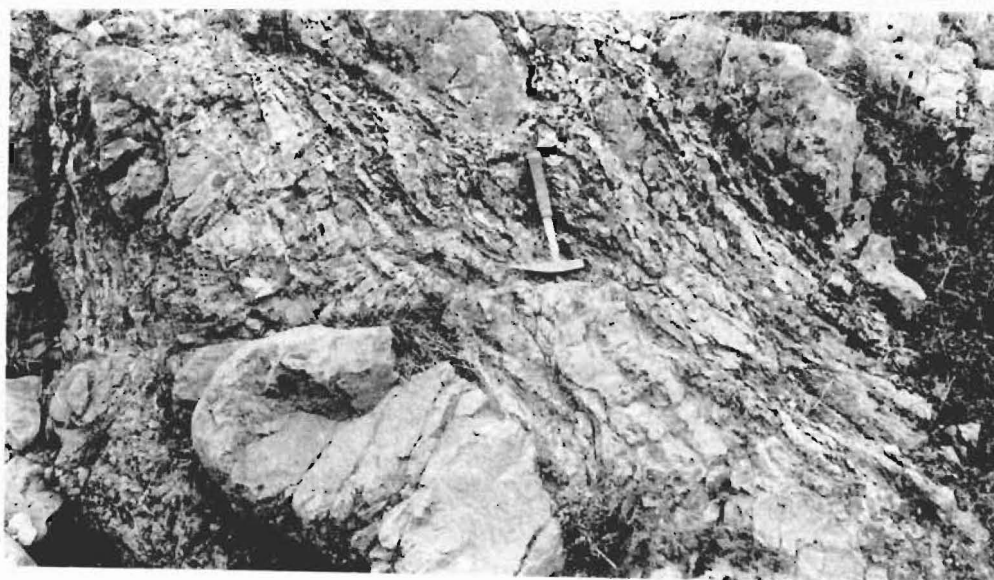
Three larger order lithologic associations have been noted. The first two are most easily recognizable within the Esk Head study area.

Thin/Thick association:

This association consists of generally sandstone dominated, thin bedded units containing isolated 1 m beds, or packets of two or three 1 m beds, of sandstone within the sequence at roughly 20 m intervals. Later stage shearing may disrupt the thin bedded units and bondinage and oblique faulting may give the thick bedded units the appearance of isolated blocks (figure 2.13). However, sequences in Valley Stream (L33/475 199), the N. Esk River (L33/473 212) and Deep Stream (L33/449 197) all suggest that the juxtaposition of thick and thin beds is depositional. Bedding remains relatively intact on either side of the thick beds or

Figure 2.11: "Welded" contact between calcareous conglomerate lens and overlying laminated sandstone. Note clast of underlying mudstone lithology (M) at top of conglomerate lens.

Figure 2.13: Thick/thin association. Single thick bed of sandstone, boudinaged to become isolated block here, within thin bedded unit.



blocks and their emplacement due to repeated shearing seems unlikely. A sandstone bed roughly 1 m thick can also be seen on the right margin of figure 2.9.

Thin/Medium association:

Locally, thin bedded and medium bedded lithologies appear to alternate in roughly 10 m packets. This is observed along the N. Esk River (L33/433 194 and L33/414 200) in sequences 60 to 80 m in total thickness (figure 2.14). Again, the relatively intact nature of bedding and absence of repeated faults or shears suggests that this is a depositional association.

Convolute laminated/coarse sandstone sequence - Ashley River:

A relatively intact, roughly 50 m thick section is noted in the Ashley River (M34/434 969) which displays interbedded units of convolute laminated sandstone/mudstone and poorly sorted coarse sandstone at the base. The sequence is illustrated in figure 2.15. The section structurally overlies a *mélange* section, which is highly faulted and contains abundant meta-volcanics. The convolute laminated and thick bedded sandstone passes upward into a section of disrupted medium bedded sandstone. Well preserved truncated ripples and flame structures (figure 2.16) suggest a consistent younging to the southwest within the section.

2.2.7 Petrography of the sandstones:

A total of 31 sandstones were examined in thin section. These were selected from areas throughout the *mélange* zone and margins and were chosen from apparently varied rock types to provide as broad a sample as possible. Thin sections were examined in order to survey 1) composition, 2) metamorphic grade and 3) small scale structural effects.

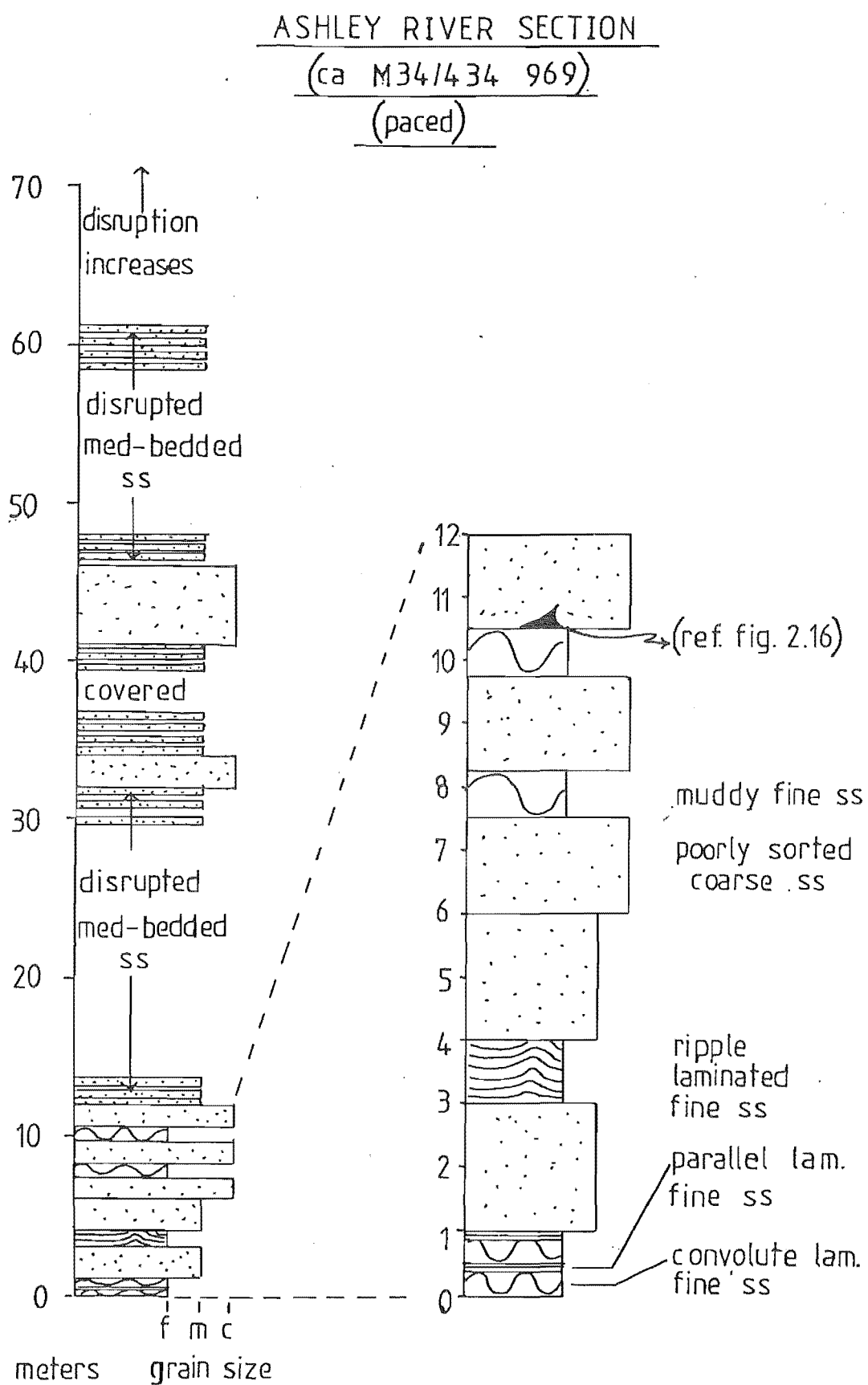
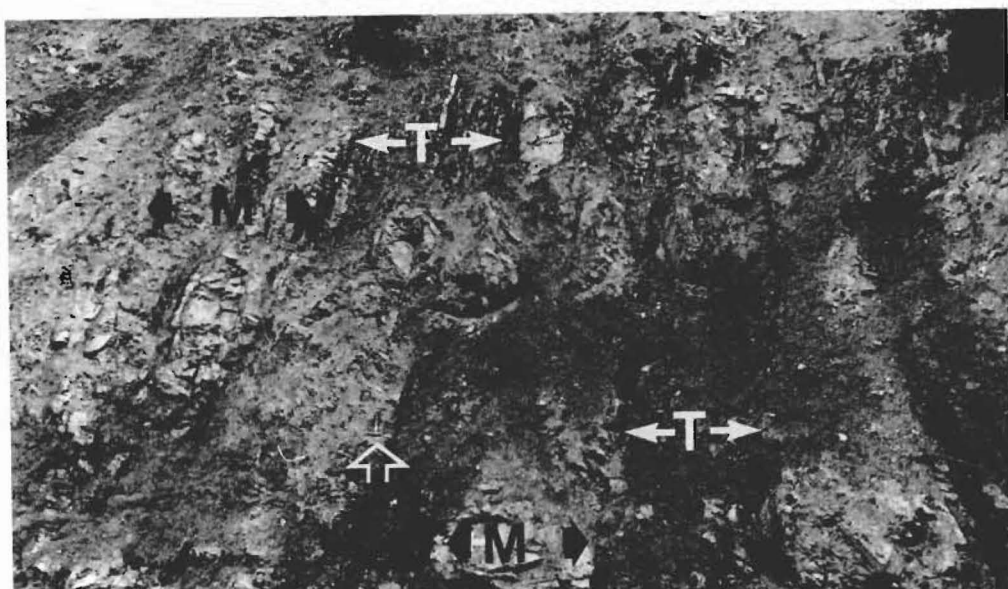


Figure 2.15: Convolute laminated sequence : Ashley River.

Figure 2.14: Alternating packets of thin (T) and medium (M) bedded lithologies. (Open arrow indicates hammer for scale.)

Figure 2.16: Flame structure within convolute laminated fine sandstone bed in Ashley River sequence (arrow indicates way up)



Composition:

Composition was estimated for all thin sections examined and six representative sections were selected for point counting (see Appendix 1). Results of point counts are presented in table 2.1 and figure 2.17. Sandstones plot in a relatively broad field which straddles the lithic feldsarenite/feldspathic litharenite classifications (Folk, Andrews and Lewis, 1970). This dispersion is due largely to the variable presence of sedimentary rock fragments (dark siltstone or mudstone). These grains may represent from zero to thirty percent of individual sandstones and as Bradshaw (1972) points out "are largely responsible for the final appearance of the rock". While sandstones are generally moderately to well sorted, the presence of these grains frequently results in a bimodal size distribution. This, and their common deformation as soft clasts suggests that they may be locally derived.

Quartz:

Quartz grains vary from relatively fresh (e.g. samples 17, 28) to embayed corroded grains showing chloritic replacement or patchy carbonate replacement (e.g. sample 103) (see diagenesis below). The quartz population is dominated by the unstrained, monocrystalline variety although strained and polycrystalline quartz is usually present in smaller percentages. Subhedral grain shapes and characteristically embayed margins locally suggest a volcanic origin (e.g. samples 1, 17, 34).

Feldspar:

The feldspar component is dominated by sodic plagioclase (albite to oligoclase based on Michel-Lévy determinations). Orthoclase is relatively rare and usually appears as highly fractured grains. Minor amounts of perthite, up to roughly 5% (sample 31) appear in many samples. This is generally mesoperthite, suggestive of a volcanic origin

Table 2.1. Modal Analysis - Representative Sandstones (expressed as percentages)

Reference number (for accompanying plot)	1	2	3	4	5	6
Sample Plot	17	156	34	90	E-1	E-53
Modal grain size (mm)	.14/.4	.35	.3/1	.25	.3/1.5	.25
<u>Quartz Total</u>	23.8	36.0	35.6	35.5	30.8	36.2
Quartz Unstrained	(13.7)	(24.1)	(24.7)	(25.7)	(23.2)	(27.4)
Quartz Strained	(5.3)	(7.0)	(.72)	(5.3)	(1.9)	(3.5)
Quartz Polycrystalline	(4.8)	(4.9)	(10.2)	(4.5)	(5.7)	(5.3)
<u>Feldspar Total</u>	15.2	22.6	14.3	19.0	27.4	30.7
Plagioclase	(14.9)	(12.6)	(12.1)	(17.0)	(27.4)	(30.4)
K Feldspar	(.1)	(10.0)	(2.2)	(1.6)	-	(.3)
Myrmekite/Granophyre	(tr)	-	(tr)	(.4)	-	-
Perthite	(.2)	(tr)	-	-	-	(tr)
<u>Rock Fragments Total</u>	37.3	17.8	37.3	23.8	23.7	16.8
V.R.F.	(14)	(7.3)	(11.9)	(16.0)	(18.8)	(14.1)
S.R.F.	(21)	(10.5)	(23.5)	(6.7)	(3.9)	(2.0)
M.R.F.	(2.3)	-	(1.9)	(1.1)	(1.0)	(.75)
Matrix*	15.4	13.6	7.8	9.2	8.4	9.0
Altered Grains	6.7	2.4	-	.68	1.2	4.3
Detrital Mica	.24	6.3	2.2	10.3	6.1	2.3
Epidote	.48	.24	.49	-	.74	.75
Zircon	.24	.48	.49	.92	.74	-
Opaques	.48	.48	1.2(Py)	-	.74	-
Diagenetic Calcite	-	-	.49	-	-	-
Recalculated Q:F:R values						
Q	31.2	47.1	40.8	45.3	37.6	43.3
F	19.9	29.6	16.4	24.2	33.5	36.6
R	48.9	23.3	42.8	30.5	28.9	20.1
Plagioclase/Total Fsp.	.98	.56	.84	.90	1.0	.99
V.R.F./Total R.F.	.37	.41	.31	.67	.79	.84

* see Appendix

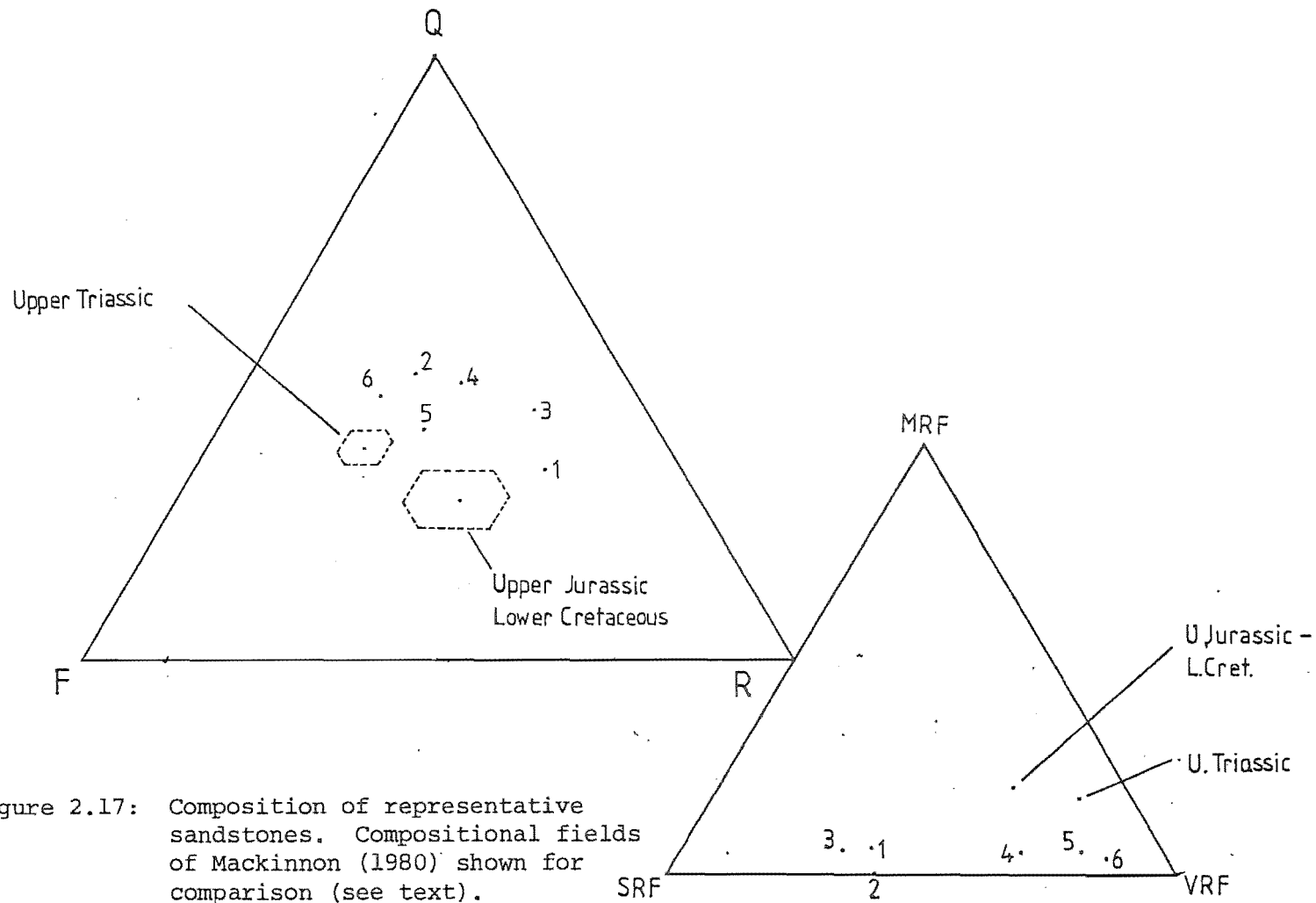


Figure 2.17: Composition of representative sandstones. Compositional fields of Mackinnon (1980) shown for comparison (see text).

(D. Shelley, pers.comm. 1982). Microcline is a common, generally relatively fresh minor component. Scattered grains of myrmekite and granophyre appear in several sections (e.g. samples 90, 103, 156).

Rock fragments:

Sedimentary rock fragments. The variable percentage of sedimentary rock fragments has been mentioned above. These grains generally represent a very coarse sand or granule mode within sandstones which otherwise range from very fine to medium sand modes. Also included in the sedimentary rock fragment category are grains of well indurated, very fine sandstone which occur widely as a minor component.

Volcanic rock fragments. Volcanic rock fragments display a variety of textures. This includes a felted to trachytic texture of feldspar microlites in a dark, devitrified groundmass. Spherulitic texture is also commonly observed. Microporphyritic grains displaying cherty alteration and dark altered grains with abundant exsolved opaques are also noted.

Metamorphic rock fragments. Metamorphic rock fragments are commonly present in small percentages. These are grains of low grade schist or phyllite.

Others:

Detrital mica is locally very abundant (e.g. samples 90, E-16). Higher percentages of mica are frequently accompanied by higher percentages of zircons. Common accessory minerals are epidote, zircon and more rarely sphene.

Diagenesis:

Commonly observed diagenetic effects include the breakdown of feldspar grains to sericite and the embayment and corrosion of a variety of grains during alteration to chlorite. Volcanic rock fragments appear to suffer various stages of a "cherty-appearing" alteration. Patchy carbonate replacement is widespread and is observed in various stages. In some cases only incipient or partial replacement of feldspars has occurred (e.g. sample 32) and in other examples wholesale carbonate replacement is evident. The apparent connection of this calcite replacement with extensive calcite veining in some samples suggests that it might be considered a metamorphic effect in part.

Quartz overgrowth is observed in several samples and feldspar overgrowth is also locally seen. Authigenic framboidal growth of pyrite has also been noted and pyrite has been observed coating quartz grains locally.

Structural effects:

Tectonic features seen in thin section will be discussed in chapter 5 - Structure.

Discussion of composition and provenance:

The six point counts shown in figure 2.17 and table 2.1 fully define the range of estimated sandstone compositions. These indicate that the overall composition of the sandstones is dominated by quartz and feldspar, with a variable and locally high percentage of rock fragments. Rock fragment composition is dominated in some samples by an influx of apparently locally derived sedimentary rock fragments (point counts 1, 2 and 3). Where this is not the case, volcanic rock fragments form the largest percentage (point counts 4, 5 and 6). Metamorphic rock

fragments are consistently sparse.

The aim of this project is not a detailed petrographic or provenance study of sandstones in the area. However the results of this reconnaissance seem to be consistent with earlier suggestions (Andrews *et al.*, 1976; Mackinnon, 1980, in press) of a source dominated by acid plutonic rocks with a strong volcanic component, and small contributions from sedimentary and metamorphic sources. Petrofacies and compositional trends for Permian to Lower Cretaceous Torlesse rocks are presented by Mackinnon (1980, in press) and the compositional fields for Upper Triassic and Upper Jurassic/Lower Cretaceous sandstones are included for comparison in figure 2.17. Point counts from this study show some similarity with Mackinnon's fields but are consistently more quartz rich. The dominance of volcanic rock fragments (in 4, 5 and 6) generally agrees with Mackinnon's findings (see daughter triangle - figure 2.17). (By convention, Mackinnon did not count the locally derived mudstone/siltstone fragments. These are included in my counts and this has shifted the rock fragment composition of points 1, 2 and 3 toward the sedimentary pole.)

The compositional field determined herein is comparable (although still somewhat more quartz-rich) to that given by Feary (1979) for the Urewera Greywacke of the North Island. Feary also noted a high proportion of volcanic rock fragments. The Urewera Greywacke is late Early Cretaceous in age and is adjacent to the Oponae Mélange.

The relatively low K feldspar percentage (0 to 10%) noted in these samples may be depositional or may have resulted from a low grade metamorphic "albitization" effect. However, this effect is seen in rocks of prehnite-pumpellyite grade or higher (Mackinnon, 1980, p.122)

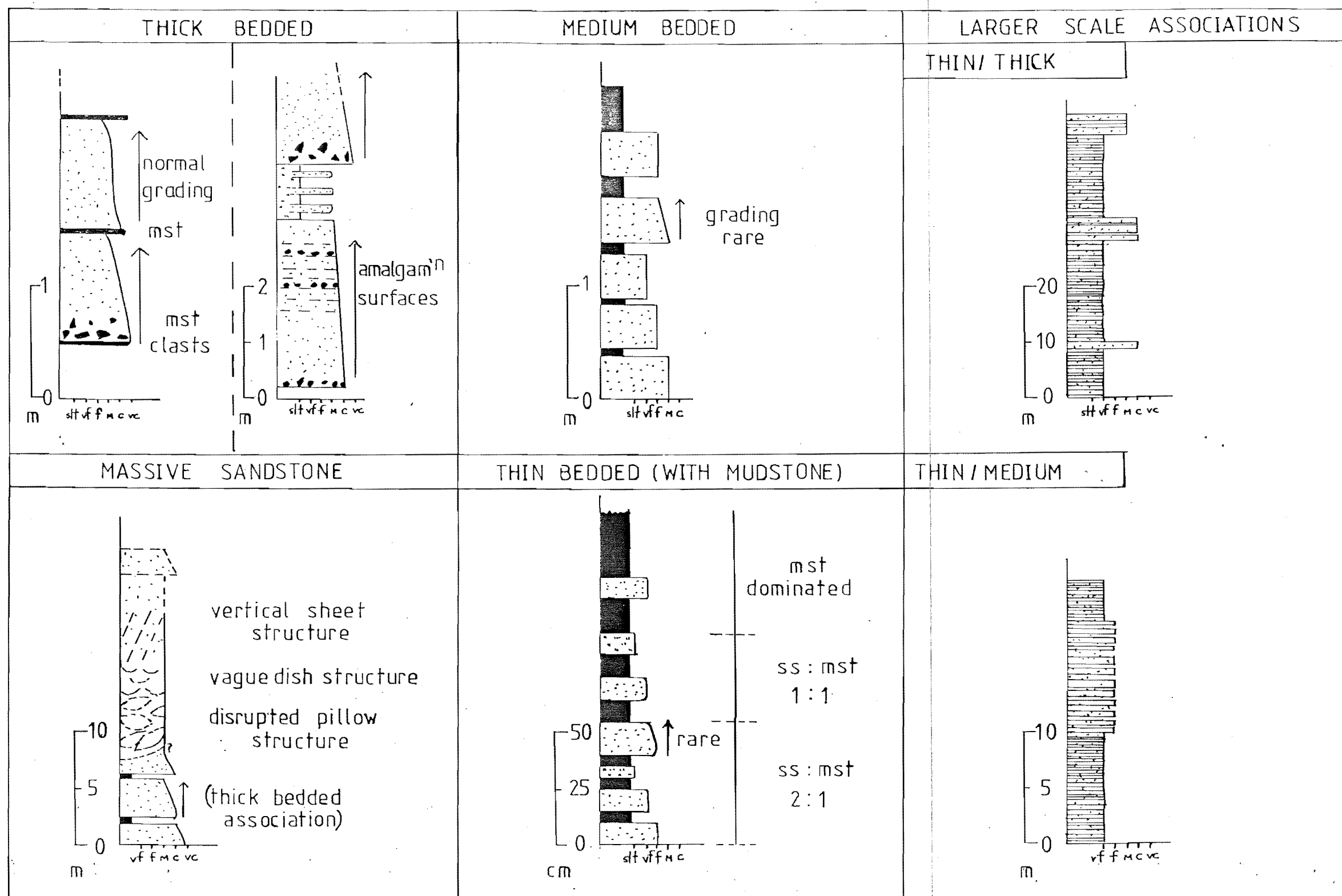
while all the sandstones of this study are believed to be only zeolite grade (see chapter 4 - Metamorphism). Moreover, none of the marginal replacement textures noted by Mackinnon (p.119) have been seen in these thin sections. Thus the low K feldspar content observed is believed to be an original depositional effect and may reflect provenance from a volcanogenic source.

2.2.8 Synthesis and discussion

The principal lithologic associations described above are summarized in figure 2.18. Lithologies similar to the above have been described in several studies of the Torlesse (see below).

A shallow marine environment of deposition has been suggested for parts of the Torlesse (Bradshaw, 1972; Andrews, 1974; Andrews *et al.*, 1976). Within the Esk Head/Okuku area however, little evidence of shallow marine deposition has been noted. Plant material, shallow water current structures, shallow marine fossils and bioturbation are all extremely rare or absent. On the other hand, deep water deposition by sediment-gravity flow processes, including turbidity currents, seems plausible for the lithologic associations described above. The grading, mudstone interbeds and locally observed parallel laminations of the thick bedded association suggest that deposition may have been by turbidity current, with only AE or ABE Bouma divisions present. Thick amalgamated beds may represent successive events of sand deposition over a short duration. The massive sandstone association appears as very thick, lenticular units. The homogenous nature of the beds, and vague dish and vertical sheet structures, may suggest deposition by fluidized sediment flow, possibly within a channel. Medium and thin bedded associations display grading only rarely. Thin bedded units, in particular, display locally low sandstone/mudstone ratios and may represent the

FIGURE 218 SUMMARY OF SANDSTONE AND SANDSTONE/MUDSTONE LITHOLOGIC ASSOCIATIONS



deposits of dilute turbidity currents.

A submarine fan environment of deposition has been suggested for several areas of the Torlesse (Feary, 1979; Beggs, 1980; Hicks, 1981; Howell, 1981; Mackinnon, 1980, in press). Sediments are too highly disrupted within the study area to allow any strong inferences about depositional environment. The lithologic associations of this section are, however, very similar to those described by Hicks (1981) from Late Triassic Torlesse sequences of the Lake Ohau area. Rocks in the Lake Ohau ski-basin region are much less deformed than those of the Esk Head/Okuku area. Hicks is able to distinguish depositional facies and relate these to a submarine fan depositional model. The suggested correlation of the lithologic associations of this study with the facies of Hicks is shown in table 2.2.

Sections provided by Hicks (e.g. figure 16, pages 224 and 225) illustrate "facies associations" suggestive of submarine fan deposition. The similarity between Esk Head/Okuku sequences and these "submarine fan facies associations" is discussed below:

- 1) The local relationship of the thick bedded and massive sandstone associations described in this study (e.g. lower Okuku River (M34/675 860) may correspond to "inner fan channel" deposits (facies association 1) illustrated by Hicks. At Ohau these are up to 70 m thick, display a broadly channelized geometry and are characterized by upward thinning sequences dominated by thick bedded and massive sandstone.
- 2) Sections described herein dominated by the thick bedded association (e.g. figure 2.2) appear similar to the broad "midfan channel" deposits (facies association 2) illustrated by Hicks. These are roughly 15 m thick, demonstrate a planar geometry, and are characterized by thick accumulations of bedded sandstone. Associated minor thin bedded

Table 2.2. Suggested correlation of lithologic associations with facies of Hicks (1981)

Lithologic Association (this study)	Characteristics	Facies: Torlesse Submarine Fan Deposits: Lake Ohau ski-basin (Hicks, 1981)
Ashley River section (figure 2.15)	thick (up to 5 m) beds of poorly sorted coarse sandstone with convolute laminated muddy fine sandstone interbeds in part	Facies A: medium to coarse grained sandstone and conglomerates, poorly sorted; thick beds (1 to 7 m, 20 m max) which are lenticular and commonly amalgamated; beds display sharp bases; occasional grading; abundant mudstone clasts; minor mudstone interbeds.
Massive sandstone association	medium sandstone, moderately sorted in massive beds ranging from 10 to 30 m thick; beds lensoid or channellized; vague dish structures; occurs as channels within thick bedded association	
Thick bedded association	medium sandstone, moderately sorted, in beds 1 to 3 m thick; common mudstone interbeds 5 to 15 cm thick; some sequences contain beds of laminated siltstone to very fine sandstone up to 2 m thick; amalgamation surfaces noted locally; normal grading commonly observed where mudstone grains/clasts abundant; sandstone beds generally display sharp bases; high sandstone/mudstone ratios	Facies B: fine to coarse sandstone, moderately sorted; beds 1 to 5 m thick, sharp bases; thin mudstone interbeds; reverse and normal grading; parallel laminations and dish structures; mudstone clasts common; high sandstone/mudstone ratios.
Medium bedded association	fine to medium sandstone, moderately sorted, in beds 20 cm to 1 m; minor parallel laminations, rare ripple laminations; grading rare; sandstone/mudstone ratio generally 2:1 to 4:1; generally thin mudstone interbeds	Facies C: coarse to fine sandstone, moderately sorted; beds 15 cm to 1.5 m; siltstone/mudstone interbeds; beds commonly display complete Bouma succession; sandstone/mudstone ratio 1:1 to 5:1.
Thin bedded association	siltstone to very fine sandstone, moderately to well sorted in beds 2 to 20 cm thick, interbeds dark mudstone; sandstone/mudstone ratio generally 1:1 to 2.5:1, grading rare	Facies D: fine sandstone, siltstone and mudstone; beds up to 40 cm thick (commonly 20 cm): sandstone/mudstone ratio commonly 1:1 Facies E: fine to very coarse sandstone, well sorted; beds up to 30 cm thick; finely interbedded with mudstone; sandstone/mudstone ratio 1:1 to 2:1, grading generally absent
	- not mapped -	Facies F: chaotic slump deposits; lenticular geometry, up to 50 m thick; intraformational breccia common
(minor mudstone sequences)	rare; occur generally as 5 m packets within thin bedded sequences; 30 m mudstone-dominated sequence seen in Stockyard Stream (M33/533 002)	Facies G: mudstone and siltstone; commonly massive; locally containing thin intervals of parallel laminations

sandstone/mudstone units are suggestive of abandoned channel fill.

3) Sequences characterized by alternating thick and medium bedded lithologies are seen in the Esk Head/Okuku area (e.g. lower Okuku River (M34/584 886)) and may have been deposited in a "fan lobe" setting (facies association 3 or 4 of Hicks).

4) The larger scale association of thin and medium bedded lithologies (figure 2.18 : thin/medium association) may represent deposition in a "midfan" setting. Here thin bedded sandstone/mudstone units represent interlobe deposits and alternate with intervals of the medium bedded association deposited by intermittently prograding suprafan lobes.

5) The larger scale association of thin bedded sandstone/mudstone with packets of thick bedded sandstone (figure 2.18 : thin/thick association) appears very similar to the "fan fringe deposits" (facies association 5) illustrated by Hicks. Here interchannel sedimentation is dominated by thin bedded sandstone/mudstone while packets of thick bedded sandstone suggest intermittent channel deposition. Intact mudstone-dominated "base of slope" sequences (facies association 6 of Hicks) are rare in the Esk Head/Okuku area.

Hicks relates the sequence of facies associations described from the Lake Ohau region to the construction and migration of suprafans on a large submarine fan system. In the Esk Head/Okuku region, sandstone/mudstone sequences have been largely dismembered in the process of mélangé formation. However, the similarity of the remaining, relatively intact sequences, with the much less deformed Torlesse sediments of the Lake Ohau area, suggests that Esk Head/Okuku sandstone/mudstone sequences are compatible with deposition in a deep water submarine fan setting.

2.3 VOLCANOGENIC ASSOCIATIONS

The common association of volcanic, limestone and chert lithologies in the Torlesse was noted as early as 1881 by Alexander McKay. Bradshaw (1972) suggests a related genesis for these rock types in discussing them under the heading "volcanogenic association" and this general approach is adopted here.

2.3.1 Volcanics

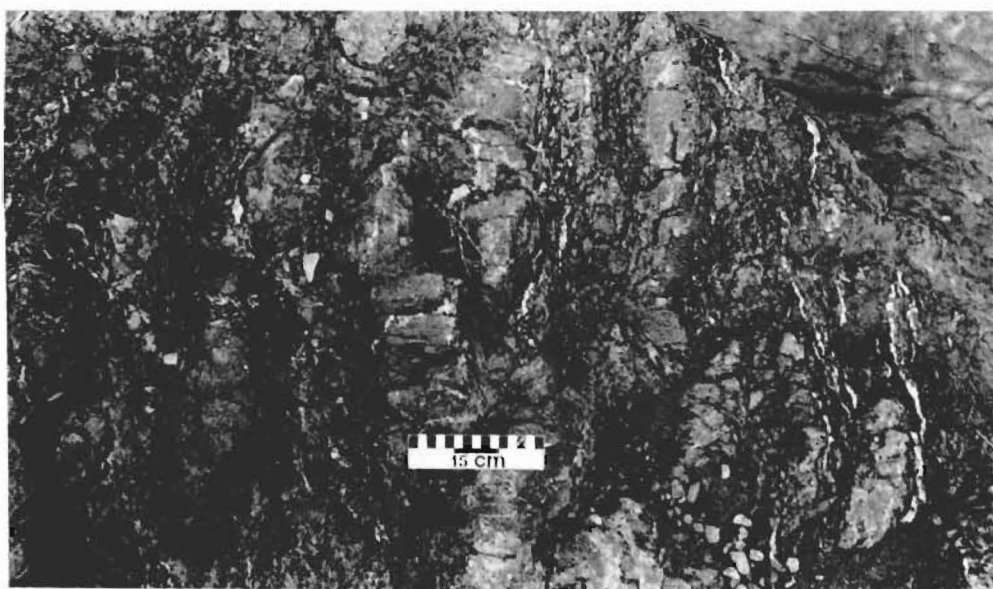
Volcanic rocks are an important element of the Esk Head mélange. Their occurrence ranges from large rafts roughly 300 m thick in the western parts of the zone (Esk Head study area) to metre size "blocks" and pebble size clasts which diminish in frequency in the eastern regions of the mélange.

The volcanics are generally highly altered. They are commonly either thoroughly hematite stained and a dull red colour or highly altered to chlorite and light green in colour. Calcite is abundant as veins, amygdale fillings, as a matrix in fragmental lithologies and as a replacement mineral. A bright green, alteration-related mineral seen in the field is believed to be epidote, but this mineral was not seen in thin section.

Volcanic units generally display a platy to irregular shear fabric (figure 2.19). While pillow forms up to 30 cm thick are strongly suggested in exposures of this kind, chilled margins or associated changes in vesicularity have not been observed. Well developed pillows are exposed to the east (Bradshaw, 1972) and are reported from the vicinity of Top of the Ladder (L33/470 152) (J.D. Bradshaw, pers.comm. 1982). The fabric of the volcanics is regarded not as purely an artifact of shearing,

Figure 2.19: Volcanics : a) irregular to pillow-like
"shear" fabric

b) irregular shear fabric. Note white calcite
veining.



but rather as a result of the tectonic exploitation or modification of an original pillow to thin flow structure. No facing directions have been established from volcanic structures.

The contacts of volcanic units with neighbouring lithologies are never clear, but are believed to be generally faulted. Two main lithologic associations involving volcanics are seen. The association of limestone lithologies with volcanics has been noted and will be discussed in the next section. Particularly in the Esk Head study area however, volcanics are commonly associated with thin bedded sandstone/mudstone units and mudstone. One such contact is shown in figure 2.20. Sandstone lithologies in this setting commonly display extensive white mineral veining and alteration (figure 2.21). This alteration has commonly advanced to the extent that sandstone beds are almost totally replaced by a secondary mineral (commonly quartz) and become a distinctive, mappable lithology. A suggestion of bedding is generally preserved and shearing, open folding and tight asymmetric folds can be seen. This folding will be discussed in chapter 5 - Structure.

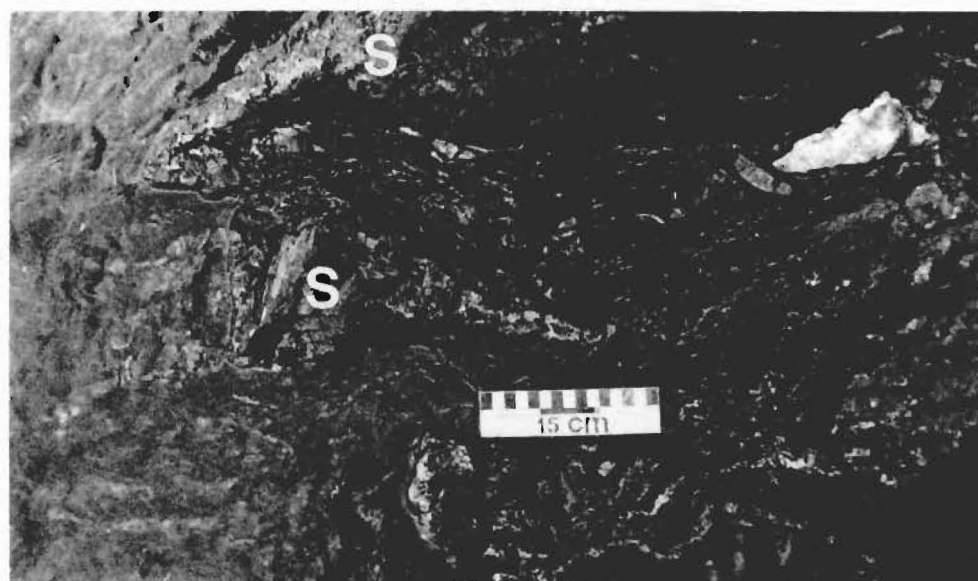
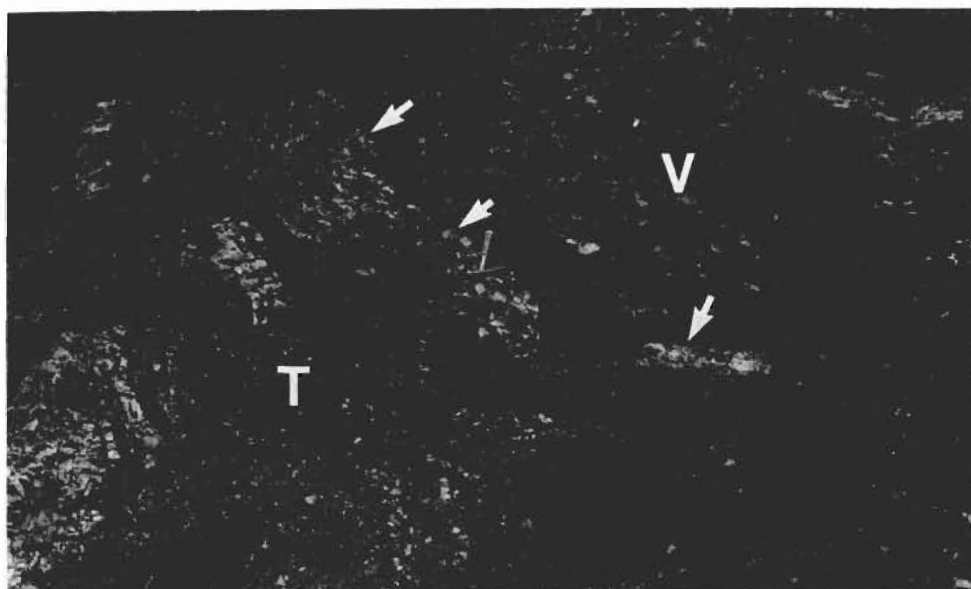
Four samples of this lithology were examined in thin section. They consist of a "host lithology" of fine or very fine sandstone extensively cut by veins of quartz (crystals up to .4 mm in diameter) and calcite. A microcrystalline replacement of the sandstone matrix by these two minerals is also observed. In one sample, later stage quartz plus laumontite veins crosscut the quartz and calcite veins.

This white-veined lithology is frequently observed sheared into the margin of volcanic units (figure 2.22). Sandstone and chert "blocks" enclosed by volcanics in the Ashley River (L34/434 977) are believed to have been incorporated in this manner, but may conceivably be xenoliths.

Figure 2.20: Contact (arrows) between volcanic (V) and thin bedded association (T)

Figure 2.21: Lozenges of highly white-veined sandstone (S) within sheared mudstone (Left margin of exposure covered by water)

Figure 2.22: Volcanic-dominated exposure with units of white-veined sandstone (arrows) sheared into margins. Note relict pillow structure (P) within volcanics. (hammer, roughly centre, for scale)



The volcanics appear to be generally vaguely pillowed lavas but dolerite, tuff, and a fragmental suite are also represented. In thin section lavas display a variable texture from intergranular to pilotaxitic to trachytic. The groundmass is generally highly altered and chlorite-rich. It may have abundant skeletal ilmenite or magnetite. Sparse olivine crystals or pseudomorphs, and relict pyroxenes may be distinguished locally. Amygdales are dominantly carbonate-filled, but two occurrences of amygdale-filling chlorite plus zeolite (natrolite) were noted in samples from above Lees Pass (sample 222) and the upper Okuku River (sample 45). Carbonate veins are common. Feldspar microlites appear to be oligoclase (Michél Levy method and R.I.) or andesine-labradorite.

A body of dolerite, approximately 100 m thick is exposed in the N. Esk River at L33/384 212. The unit is bounded by vesicular lava on the east and volcanic rich *mélange* on the west. Here phenocrysts of plagioclase up to 1 cm long are contained in a dark, partly hematite-stained groundmass. In thin section, phenocrysts and some glomeroporphyritic aggregates occur in a highly altered, devitrified groundmass. This displays an intergranular texture and includes olivine (and carbonate pseudomorphs after olivine) and abundant magnetite. The feldspar phenocrysts appear to be largely oligoclase in composition although some labradorite is also observed. This dolerite body is similar to that described from Jack's Saddle, to the east, by Bradshaw (1972).

Tuffaceous lithologies appear to be of two types. A coarser hematite-stained tuff is very rich in shell material. It is essentially a limestone and will be discussed under that heading below. A finer tuff is carbonate rich, may be locally tan-weathering, but is generally moderately to highly chloritized and appears green in outcrop. It consists of very fine sand size glassy volcanic fragments with sparse microlites,

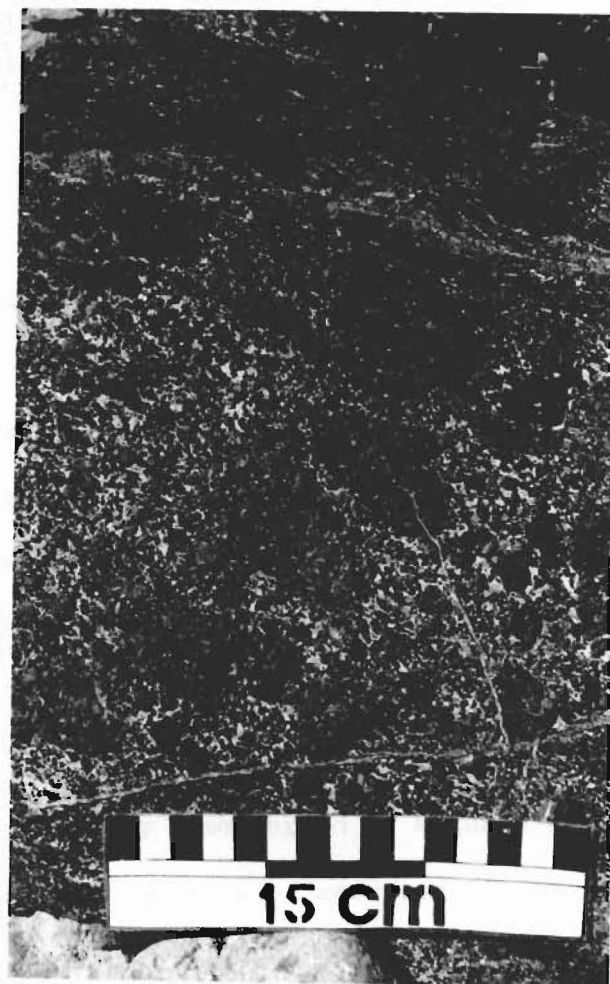
in a carbonate matrix. Calcite and quartz veins are frequently observed. These tuffs occur as poorly defined zones up to roughly 70 cm thick within volcanic units. No primary structure has been observed within them. Many of the totally altered, chlorite-rich green zones which occur within hematite stained volcanic units may represent tuff horizons, now altered beyond recognition. These may have been altered to chlorite very early due to an original high permeability.

Fragmental textures are apparent in several localities. In Punanui Stream (M34/537 976), rounded to angular cobbles of highly vesicular lava occur within a matrix of highly sheared, hematite-stained, non-vesicular lava and minor red mudstone (figure 2.23). Upstream from this locality (M34/532 975) volcanic breccia is seen in a large angular block of float, but was not found in place. Here angular fragments of lava approximately 5 mm in diameter, and scattered cobbles up to 4 cm, are surrounded by a carbonate matrix (figure 2.24). In thin section, lava fragments appear as a pilotaxitic basalt with both feldspar microlites and olivine crystals almost totally replaced by carbonate. Some stretched, chlorite-filled amygdales can be seen. A similar lithology occurs as irregular rounded boulders and cobbles, along with cobbles of vesicular lava and sandstone, in an isolated exposure of sandy conglomerate in the South Branch Waipara River (M34/596 979) (figure 2.25). Volcanics exposed above Lees Pass (ca. M34/596 966) include finer fragmental rocks. Here rounded to angular glassy fragments of basalt up to 5 mm occur within a less obvious carbonate matrix. These fragments have sparse zeolite-filled amygdales.

Minor red mudstone is locally associated with volcanic units but is not well developed in the study area. Red mudstone is irregularly distributed in a volcanic exposure at the mouth of Woollies Stream

Figure 2.23: Rounded cobble of highly vesicular lava within matrix of highly sheared non-vesicular lava and minor red mudstone

Figure 2.24: Volcanic breccia : angular fragments of lava surrounded by a carbonate matrix (float - Punanui Stream)



(L33/431 193) in the Esk Head study area. Since this minor lithology is always associated with volcanics and frequently difficult to distinguish from highly altered and weathered volcanic material, it is mapped as part of the volcanics.

2.3.2 Limestones

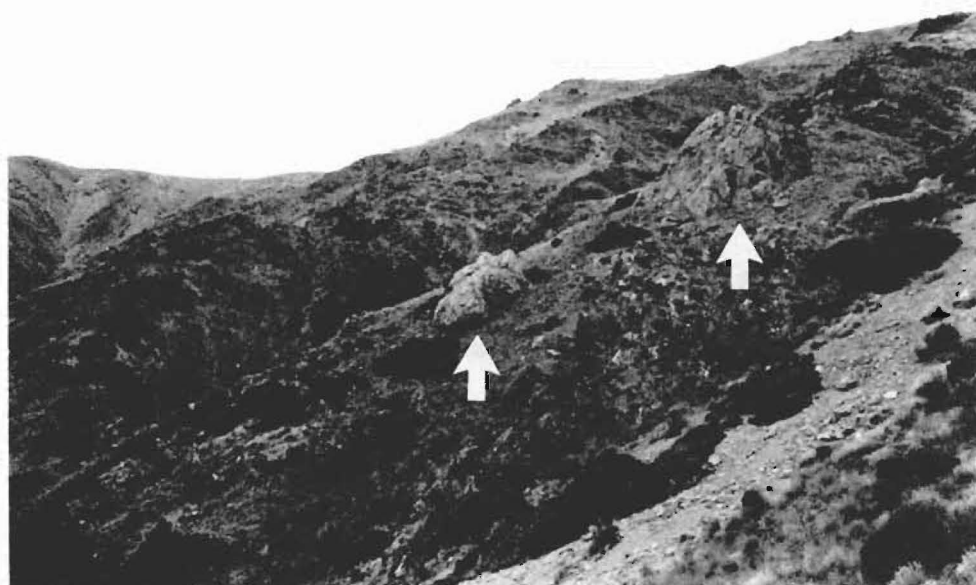
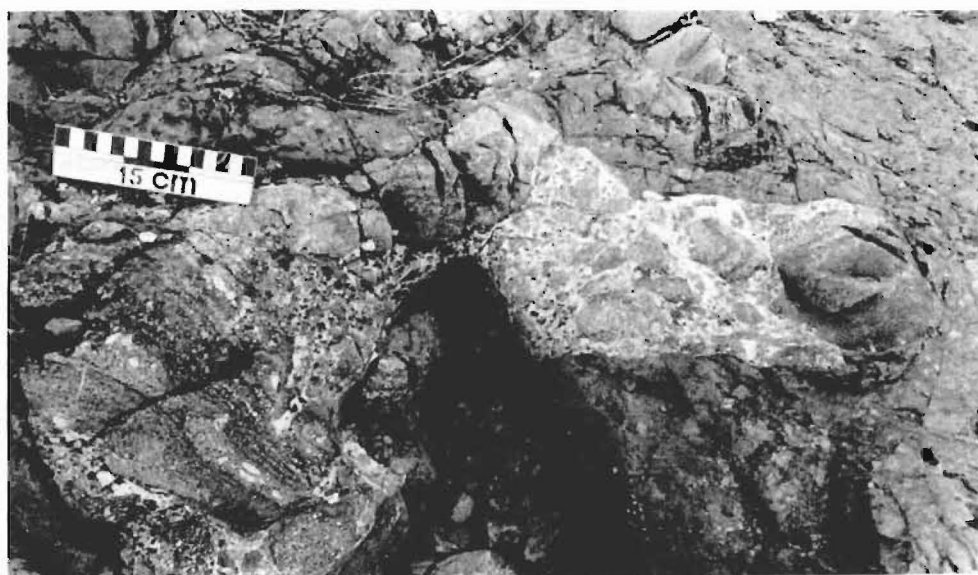
Limestones examined within the Esk Head/Okuku area occur largely as isolated "blocks" within *mélange*. Blocks vary in size from large masses approximately 5 x 10 x 15 m (Esk Head [S69/f563]; L33/481 171) (figure 2.26) to cobble or pebble size "blocks" surrounded by *mélange* matrix or within conglomerates. The close relationship between limestones and volcanics has been noted by Bradshaw (1973). Within the study area, this includes two notable localities where limestone masses are actually cemented to volcanic material: in the Okuku Range (ca. M34/594 962; [S67/f513]) and near Esk Head (ca. L33/478 164) (Bradshaw, 1973).

Various degrees of recrystallization are displayed by limestone lithologies in the area. These range from very well preserved, richly fossiliferous biomicrites (e.g. the above mentioned S67/f513) to highly recrystallized limestones, dominated by sparry calcite with sparse, partially recrystallized shell material apparent only in thin section (e.g. a 1 x .5 x .25 m limestone block located in the South Branch Waipara River at M34/619 966). No pattern governing the disposition of this effect has been discerned. It has been suggested that proximity to master shear planes during some period of *mélange* formation, may have resulted in locally high degrees of recrystallization.

Three main lithologic groupings are distinguished among the limestones examined. These are characterized as 1) biomicrite or biosparite, 2) tuffaceous, 3) micritic.

Figure 2.25: Irregular boulders of volcanic breccia within sandy conglomerate (South Branch Waipara River)

Figure 2.26: Two larger isolated limestone blocks (arrows) in *mélange*, north flank Esk Head (fossil locality S60/563)



The biomicrite group includes richly fossiliferous blocks such as S67/f513 (Okuku Range), the Esk Head block (S60/f563) and other more recrystallized versions of these, such as the South Waipara example mentioned above. The dominant fauna in these blocks is the bivalve *Monotis Richmondiana*. Parts of the Esk Head block are also rich in the bivalves *Halobia* sp.cf. *hochstetteri* and *Mantacula problematica* (Speden, 1975). Shells are generally disarticulated and generally broken, although beautiful intact *Monotis* valves can be seen at S67/f513 and do occur within S60/f563. In thin section, the fibrous, lamellar and foliated structure of bivalve shells is evident even in more highly recrystallized samples (e.g. numbers 173, 193). Scattered intraclasts, sparse crinoid ossicles and sparse detrital sandgrains are noted in a thin section survey of this lithologic group. A micritic matrix is generally observed although parts of the Esk Head block appear to be poorly washed biosparite. Textually, these limestones are packstones or grainstones. The disarticulated and broken shells appear to have been transported. These, the sparse intraclasts and detrital grains may have been derived from a relatively shallow environment, transported, and deposited in a deeper, quiet water environment, as suggested by the generally abundant micritic matrix. If such relief is envisaged, the juxtaposition of fossil zones in the Esk Head block (discussed by Speden, 1975) may be related to much later sediment movement down the same slope.

The tuffaceous lithology is most clearly seen in an angular block of float in the Okuku River at M34/586 924. This is reddish, hematite-stained and crudely laminated on a 2 to 3 cm scale. It displays alternating zones of 1) coarse to very coarse grains of volcanic rock fragments, generally well rounded, with minor shell material and 2) abundant, partially recrystallized shell material, broken in part, in a matrix of silt-size tuffaceous material. The disarticulated valves are oriented

parallel to bedding, convex side facing in both directions within the same lens (figure 2.27). Surfaces etched in HCL display ribbed shell casts, suggestive of *Monotis*, within tuffaceous material. Sparry calcite is abundant. Thin section examination reveals lenses of abraded and well rounded echinoderm fragments (plates and rare spines) plus sparse benthic foraminifera. Well rounded glassy volcanic rock fragments with abundant feldspar microlites and some free feldspar lathes are evident in various stages of replacement by calcite. The abrasion and rounding of echinoderm and volcanic rock fragments probably occurred in a high energy shallow marine environment. No grading is evident within the above described lenses and it seems likely that deposition occurred in a shallow water environment subject to current action.

More highly recrystallized and stylolitic examples of this lithology have been collected from isolated blocks in the Okuku Range above Lees Pass, close to S67/f513. A similar lithology from the Studleigh Range is discussed and figured by Petrie (1974, pp 13-15).

Angular to rounded "blocks" of buff-weathering micrite occur as a common minor component within mélangé and also within the polymict conglomerates described in chapter 3. Fractures within these are commonly filled with dark chert and some "blocks" are partially silicified (figure 2.28). The silica veining and apparent silicification of some micrites may suggest a deep water environment. Bernoulli and Jenkyns (1974) describe Mesozoic examples of cherty replacement in pelagic calcisiltites from the Alps.

Some tan-weathering limestones regarded as micrite have a recrystallized "felted" microspar texture in thin section. These also frequently display a chloritic matrix in part and are commonly brecciated

Figure 2.27: Tuffaceous shelly limestone. Note alternating shell-rich and volcanic-rich layers.
(float - lower Okuku River)

Figure 2.28: Micritic limestone "block" in *mélange* displaying dark cherty fracture fillings (arrows)



along heated fractures, into cm-size fragments. These lithologies may have originated as tuffs and undergone complete carbonate replacement.

Deposition of micrite need not be restricted to deep water settings. Micritic limestone may be deposited in any low energy environment which is provided with sufficient lime mud. The "calcareous conglomerate" described earlier is dominated by rounded to subangular clasts of micritic limestone, many of which are actually intramicrite and contain 1 to 2% detrital grains. In this case, initial deposition of intra-micrite may have occurred in a sheltered, relatively shallow water setting. Subsequently, these beds were ripped up and clasts transported downslope in a debris flow, with a sandy micritic matrix.

2.3.3 Cherts

Most cherts seen in the study area are distinctly hematite-stained and reddish. Other chert blocks noted in *mélange* range from pale buff to pink to pale purple. Many cherts appear to be strongly related to volcanics. Some are obviously replacements of volcanic rocks. Here replacement is seen as patchy elliptical areas up to roughly 30 cm in length, to vaguely bedded units up to roughly 1 m in thickness, within a volcanic sequence. These cherty areas are generally strongly silica veined, but otherwise appear massive. Bradshaw (1972) reports some relict igneous textures from thin section examination of similar "massive cherts".

Cherts bedded on a scale of 1 to 3 cm are also seen (figure 2.29). Bedding is defined by mm thick, dark friable muddy "interbeds". One of the best examples of this lithology is a large, isolated raft of strongly hematite-stained chert, immediately northwest of The Brothers homestead (ca.M34/585 990). The chert is dominantly thick bedded to massive but contains scattered 1 m intervals of thin bedded chert. These display cm

scale bedding which is commonly disrupted by open folding or fracturing. The unit as a whole forms a ridge with scattered outcrop along its length. Outcropping thickness ranges up to roughly 7 m. Although exposure of sandstone along the ridge (M34/583 993) breaks the apparent continuity of chert exposures, the unit is at least 750 m in length and may be much longer. The mapping of Warren (1955) suggests that the same chert extends south into the Okuku Range.

Samples from this exposure display the only radiolaria found to be observable in hand specimen. These are frequently confined to individual cm scale beds, which are interbedded with barren intervals. In thin section, the radiolaria are seen as round molds, totally replaced by microcrystalline quartz. Abundant clear crystalline quartz veins cut across the lithology. Wise and Weaver (1974) suggest that much of the quartz veining and replacement seen in pelagic radiolarian cherts may be an early diagenetic effect. Attempts were made to extract radiolaria for dating from chert samples collected throughout the study area. These were unsuccessful (see Appendix II).

While extensive quartz veining and replacement may have destroyed initial textures in many cherts, it appears that the cherts of this study area may have two main origins. Some appear to be deep water radiolarian cherts while others may have resulted from the action of silica-rich fluids, possibly related to volcanic exhalations. Complex combinations of these two probably occur.

2.3.4 Synthesis and Discussion

Volcanic, chert and limestone lithologies represent the exotic elements of the Esk Head Mélange. There is no evidence to suggest that they are interbedded with any of the sandstone lithologies within this

area. Rather they appear as discrete blocks in mélangé.

I regard the volcanics and associated cherts of the Esk Head Mélangé as pieces of original oceanic basement, following the suggestion of Sporli and Bell (1976) who refer to similar rocks of the Ruahine Range, North Island. They further suggest that "... cherts and the uppermost, least competent part of the volcanic basement would be selectively sheared off and included in the [local Pohangina] mélangé" during postulated telescoping of the local basement and overlying clastic succession. This view has found support in a study of similar setting in the Raukumara Peninsula, North Island (Feary, 1979), and in a wide-ranging examination of Torlesse metabasalts on the South Island (Pringle, 1980). The volcanics examined by Pringle display geochemical affinities with both tholeiitic and alkali basalts and he suggests a general origin as ocean floor basalts or intraplate guyots. Within the Esk Head, the thin bedded, mudstone-rich lithologies associated with the volcanics are regarded as distal clastic facies deposited on oceanic basement. These presumably have remained connected to the basement while it was tectonically broken, sheared and incorporated into the Esk Head Mélangé and adjacent subterranean.

Radiolarian cherts are a well documented component of pelagic environments (Jenkyne, 1978) and it seems that the cherts of this area were deposited on pillow lava and form an integral part of the original oceanic basement. Bernoulli and Jenkyne (1978) describe extensive Triassic radiolarites, black shales and varicoloured marls associated with volcanic rocks throughout the Alpine-Mediterranean region.

It has been suggested that the limestone/volcanic association noted in the Torlesse (Bradshaw, 1972, 1973; Pringle, 1980) and in Mesozoic North

Island terranes (Sporli and Bell, 1976; Feary, 1979) has been produced by the carbonate capping of seamounts or intraplate guyots. Evidence from the Esk Head Mélange tends to support this contention. Several of the limestone lithologies described above are associated with the volcanic basement, but bear some relationship to shallow water conditions. This implies topographic basement highs. The presence of tuffaceous limestones suggests that carbonate deposition may have accompanied or immediately postdated the building or fragmental activity of the volcanic high.

Limestones within the mélange represent isolated minor components (certainly less than 5% by volume). This would suggest that the source of the limestones was itself areally small or small by volume, if extensive destruction of pre-existing limestones during mélange formation is ruled out. Thus isolated seamount caps as opposed to extensive shelf carbonates appear to be a more reasonable source for limestones now seen in mélange.

Karig *et al.* (1970) report modern sediment-capped guyots from the Pacific region. These may display calcarenite or similar high energy facies immediately atop volcanics, and overlain by generally much thicker "pelagic calcareous ooze". Mathews *et al.* (1974) describe drowned Cretaceous rudistid reefs on mid-Pacific and Japanese guyots. From the Jurassic of the Alpine-Mediterranean region, Bernoulli and Jenkyns (1974) describe condensed successions deposited on submarine highs or seamounts. These include pisolitic ironstone, manganese nodules and crusts, biosparites involving various fauna including bivalves, pelagic pelmicrites and others.

2.4 YOUNGER ROCKS

2.4.1 Dykes

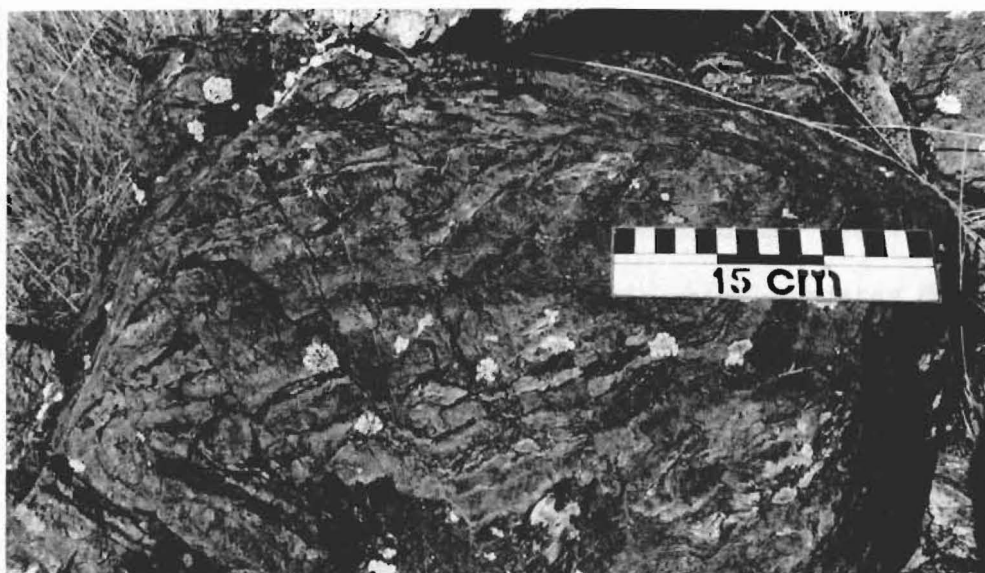
The mélange zone is cut by numerous undeformed, generally north-east trending, steeply dipping dykes (figure 2.30). These are usually notably fresher than the surrounding country rock. Dykes vary in thickness from roughly 30 cm to 3 m. The thicker dykes display chilled margins, and may range from a medium crystalline core to a fine crystalline margin. These dykes are generally dark in colour. They commonly display medium to coarse crystals of biotite and locally pyroxene and related dykes have been termed lamprophyric.

Thin section examination of medium crystalline dykes reveals euhedral to anhedral lathes of labradorite up to .4 mm and anhedral augite in an intergranular groundmass of feldspar microlites, biotite, brown hornblende and abundant magnetite. Finer crystalline dykes display an intergranular texture of similar composition and commonly record extensive carbonate replacement. In hand specimen, dark fine crystalline dykes display a spheroidal or knotted texture on a 5 mm scale. It has been suggested that this is a weathering phenomenon (S.D. Weaver, pers. comm., 1982).

A dyke noted in Stockyard Stream (M33/533 001) is highly altered and tan weathering. In thin section, very extensive carbonate replacement is noted. Calcite forms scattered pseudomorphs after olivine in a fine crystalline groundmass which displays patchy calcite alteration and veining. This calcite alteration may be related to the proximity of a major late stage fault. Reddish "hairlike" carbonate veinlets are noted in the surrounding country rock.

Figure 2.29: Block of cm scale bedded chert

Figure 2.30: Steeply dipping late stage dyke (Okuku River)



Xenoliths of muddy mélangé material are noted in a dyke in stockyard Stream (M34/536 999). Bradshaw (1973) mentions another example in the Okuku River (M33/557 008).

These dykes are probably related to the Mandamas Syenite complex (see figure I.1) (Warren, 1955; Bradshaw, 1973) which predates deposition of the local Haumurian Coal Creek Formation (Seoon, 1969). This provides an upper age limit to mélangé formation.

2.4.2 Tertiary sediments

South of the Okuku study area, undisturbed Upper Cretaceous sediments overlie the Esk Head Mélangé. These are exposed in the West Branch of the Grey River and the Karetu River (Mason, 1941).

No new Tertiary inliers were encountered in the course of this study. A block of moderately indurated shelly calcarenite, strongly suspected to be Tertiary, was found in float in the North Esk River at L33/403 202, but not located in place. At present, no Tertiary inlier is mapped within the catchment upstream from this locality.

CHAPTER THREE

ROCK TYPES CHARACTERISTIC OF THE ESK HEAD MÉLANGE

1.1 POLYMICT CONGLOMERATE

Polymict conglomerates exposed within the study area are regarded as key elements of the mélange. They are best developed and best exposed in two main areas along the Okuku River, in the vicinity of M33/534 017 (upstream section) and M33/563 014 (downstream section) (figure 3.36a) and b) and geologic map). The conglomerates occur in beds ranging from 2 to 50 m in thickness (and locally as thinner lenses described below). They are moderately to poorly sorted and consist of rounded to angular, pebble to boulder clasts with variable percentages of a medium sandstone to dark mudstone matrix.

Listed in order of decreasing abundance, the clasts are composed of: 1) grey medium sandstone; clasts both angular and rounded, in part displaying evidence of soft sediment deformation, 2) tan weathering, very well indurated fine to medium sandstone; generally very well rounded and believed to be concretions in part, 3) mudstone, both a) very dark angular clasts ranging up to 3 cm in longest dimension and b) dark, soft sediment deformed clasts up to 5 cm, 4) limestone, dominantly subrounded to subangular clasts of tan-weathering micrite, but also including subangular clasts of recrystallized sparry calcite, 5) green metavolcanics, generally subrounded (locally absent), 6) reddish (hematite-stained) chert. Other minor components include rounded pebbles of calcite, quartz and sparse grains up to 1.5 cm of framboidal pyrite. Locally the conglomerate also contains sparse, well rounded boulders of a granule to pebble conglomerate which display a high percentage of rock fragment grains and a strong platy internal fabric (figure 3.1).

Grading is not commonly observed although conglomerate units locally fine upward from boulder or cobble dominated at the base to pebble dominated at the top (e.g. M33/564 027). The lower part of each unit displays no apparent fabric, but a vague platy fabric appears in the upper part of several units. No imbrication has been observed.

These conglomerates form a part of larger sequences which contain other associations described below. The lower contact of individual conglomerate units is seen to be either uncomfortable with underlying units or marked by minor scours (e.g. M33/564 015). In the downstream section, several units of conglomerate pass transitionally upward into *mélange* matrix associations. This is demonstrated in figures 3.2, 3.3 and 3.4. Rounded boulders of the conglomerate also appear within the overlying *mélange* matrix association (figure 3.5).

In the upstream section, conglomerates are strongly associated with laminated or convolute laminated units. Conglomerates locally appear as irregular beds only a few cm in thickness (figure 3.6). Thicker beds display "welded" contacts with overlying laminated units (figure 3.7) and pebble conglomerate units locally display a strong platy fabric. As described in the downstream section, conglomerates here also pass transitionally upward into *mélange* matrix associations. Sparse rounded boulders also appear therein.

Three occurrences of more highly deformed polymict lithology are noted in the Esk Head study area. Here bedding relationships are not clear and all localities are believed to represent discrete "blocks" within *mélange*. On the N. Esk River (L33/458 208) approximately 10 m of conglomerate is noted. Here it contains rounded clasts up to 20 cm in longest dimension. Major constituents are grey medium sandstone,

Figure 3.1: Polymict conglomerate containing conglomeratic boulders (C). Note both rounded and angular clasts.

Figure 3.2: Lithology intermediate between polymict conglomerate and mélange matrix.

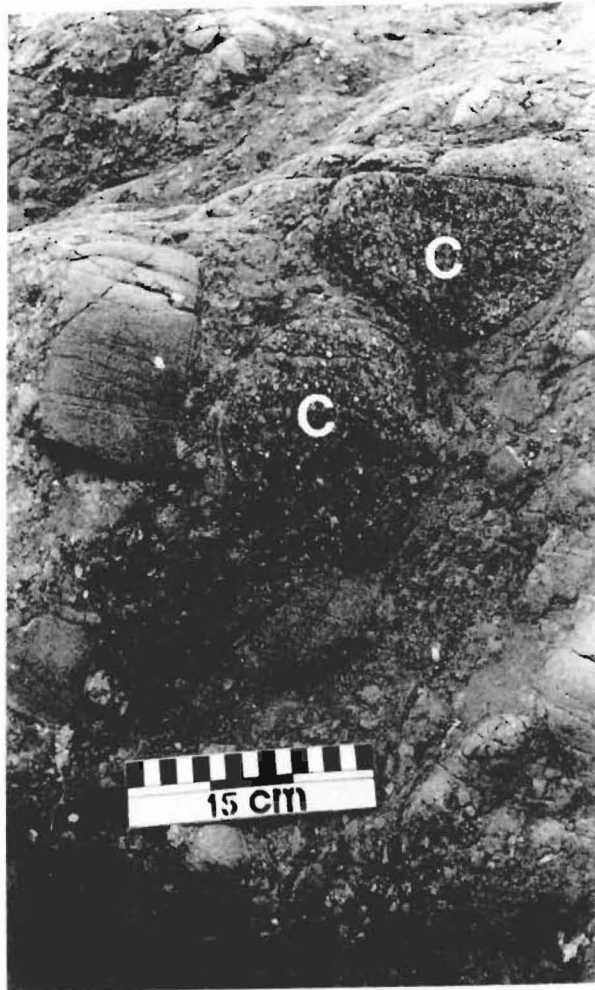


Figure 3.3: Transitional upper contact of polymict conglomerate with blocky mélange matrix: conglomerate (C) on left, approximate contact = dashed dark line, (indicated by arrows), mélange matrix (M) on right.

Figure 3.4: Transitional upper contact of polymict conglomerate: Main body of conglomerate to left of photo; one large rounded sandstone boulder (B) in photo centre surrounded by mudstone dominated matrix (M).

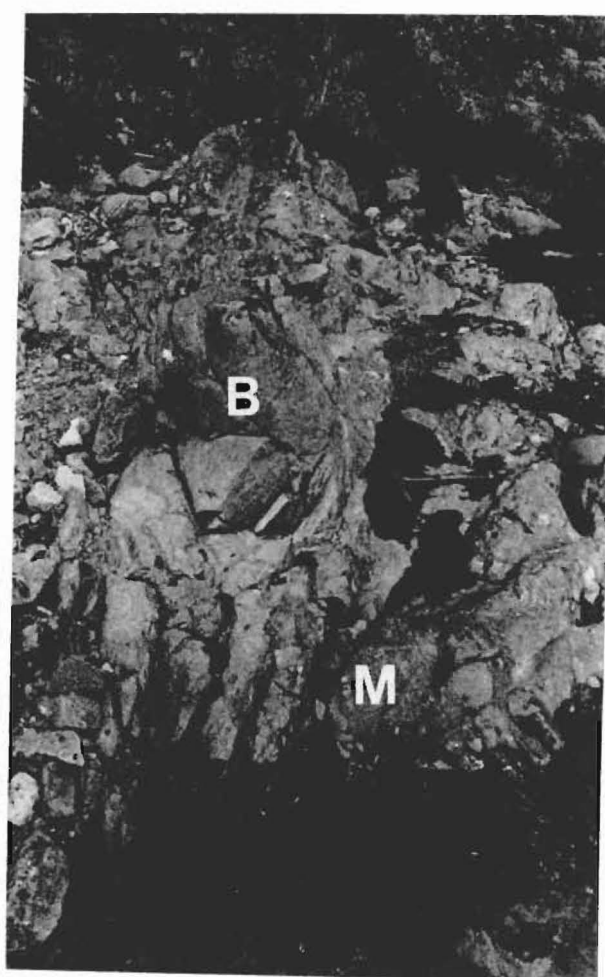
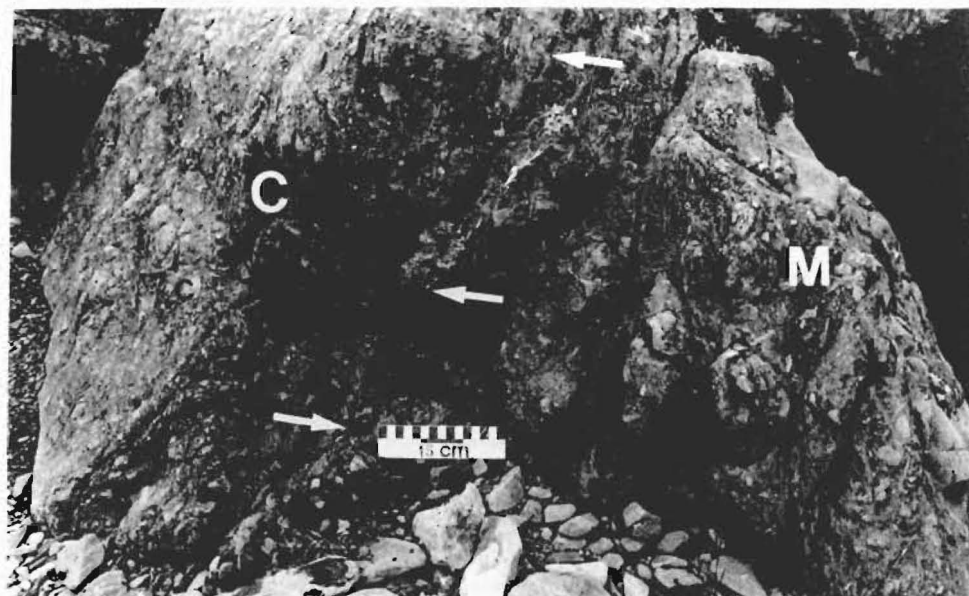


Figure 3.5: Rounded boulders of polymict conglomerate (B) within mélangé matrix.

Figure 3.6: Thin lens of polymict conglomerate within laminated lithology.

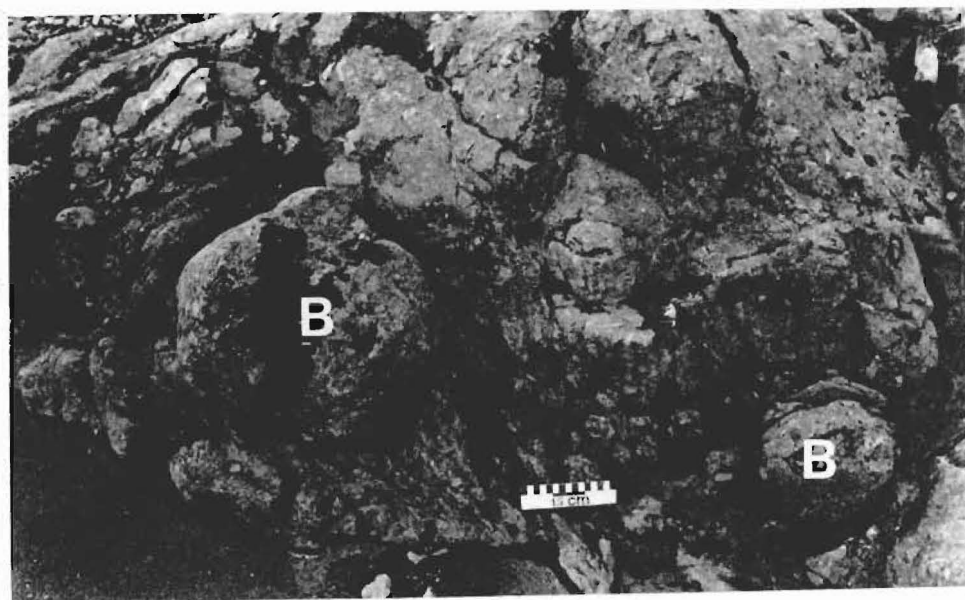
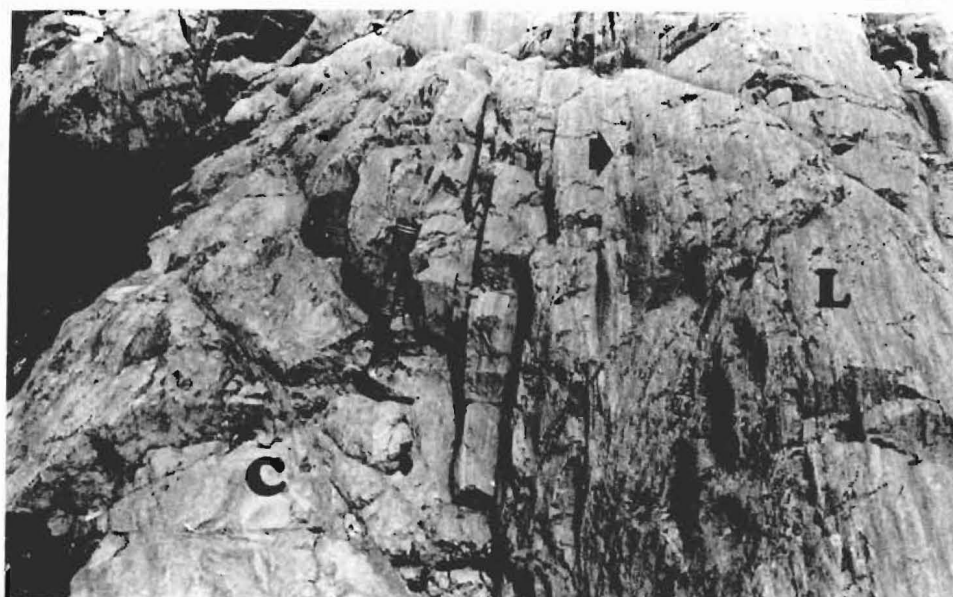


Figure 3.7: "Welded" contact between polymict conglomerate (C) and laminated lithology (L). (arrow indicates way up)

Figure 3.8: Flattened polymict conglomerate (N. Esk River)



micritic limestone and mudstone, and minor constituents are green meta-volcanic and quartz, both occurring as well rounded pebbles. The conglomerate displays a strongly flattened fabric (074/80N) (figure 3.8). Mudstone clasts are locally flattened into "ribbons" or "plates" but no new mineral growth is noted in "strain shadows" of other clasts. A more angular polymict lithology occurs apparently as a several metre block within mélangé on the South Branch Hurunui River at L33/478 213. Here the lithology has an angular brecciated appearance in outcrop. In polished slab the dominant lithology is seen to be siltstone and very fine sandstone which is soft sediment deformed. Other clasts are pressed in to the margins of the siltstone/sandstone and it is squeezed into fractures in other lithologies (figure 3.9). Other constituents are rounded pebbles of fine sandstone, angular dark mudstone clasts and angular to rounded pebbles of green metavolcanic, chert and limestone. Another apparently isolated, 10 m square block of conglomerate is noted near the eastern margin of the mélangé zone (M33/528 202). Clasts are dominantly angular pebbles to cobbles here, with abundant mudstone clasts, quartz and minor grey limestone.

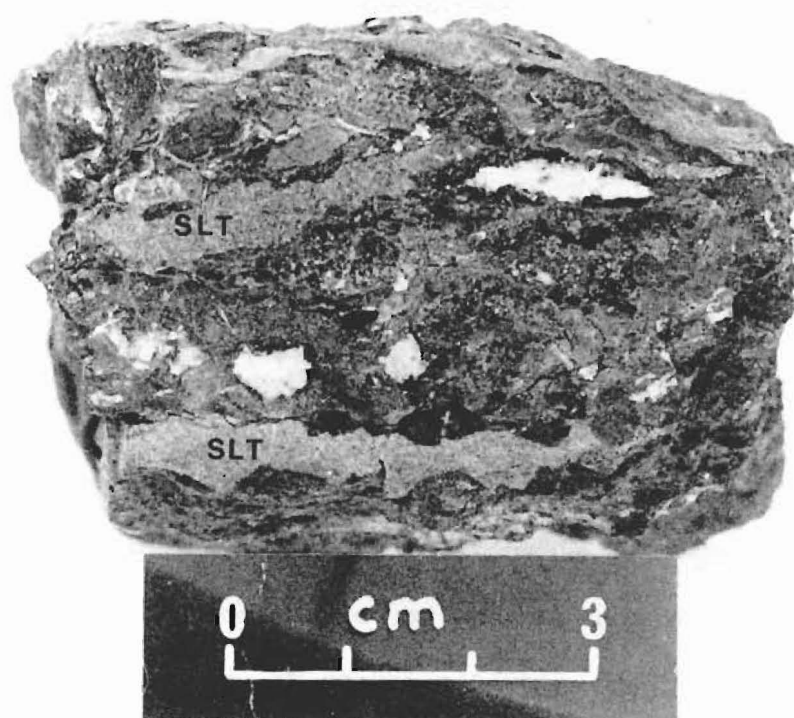
Conglomerate is also noted in the Okuku River (M34/578 938) where it occurs as an isolated metre scale block within mélangé. Here the conglomerate is dominated by pebble to boulder clasts of sandstone, but contains sparse well rounded pebbles of chert roughly 1 cm in diameter. Clasts range from well rounded to a highly elongate, flattened and soft sediment deformed sandstone body (figure 3.10).

1.2 LAMINATED ASSOCIATION

This lithologic association is characterized by laminations ranging from 2 to 10 mm of dark silty mudstone and siltstone or very fine sandstone. In some areas, sandstone/siltstone appears to dominate (figure 3.11), but

Figure 3.9: Polished slab : flattened polymict conglomerate
Note flattened siltstone bodies (SLT)

Figure 3.10: Conglomerate (block) with soft sediment
deformed sandstone body (SS); block in
mélange (lower Okuku River).



generally sandstone(siltstone)/mudstone ratios of 1:1 or 1:2 are seen (figure 3.12). The lithology is commonly very well indurated. The association with other lithologies will be discussed below. Laminae are commonly disrupted by soft sediment faults or soft sediment folding. Figure 3.13 illustrates the displacement of laminae (in both senses) by a number of small scale faults which die out along their length. A small scale injection of fine to very fine sand should also be noted. A field example is illustrated in figure 3.14. Laminae are commonly folded by open to close, soft-sediment folds and locally contain several metre units of convolute laminated siltstone/mudstone (e.g. Okuku River M33/558 022). These are frequently accompanied by sparse, generally subangular clasts, 10 to 20 cm in diameter, of coarse sandstone to conglomerate (figure 3.15). Larger scale soft sediment folding is shown in figure 3.16.

Several thin sections and slabs of this lithology were examined to establish whether some of the lamination might, in fact, be a tectonic foliation. Most samples display a mode of medium silt with laminations of very fine sandstone and dark clays or platy opaques. Subangular grains of quartz, feldspar and volcanic rock fragments are noted. Several samples contain relatively abundant zircons which frequently appear in laminations dominated by heavy and opaque minerals. A platy fabric is generally defined by the alignment of elongate detrital grains and detrital micas. Grading is locally noted within laminae. Truncated laminations and a suggestion of disruption by burrowing are noted in sample 118. Sample E-76 displays disruption by small scale normal and reverse faults and small scale "rotational slumps". In several samples, sandstone and mudstone appear to have deformed in an equally ductile manner and frequently show small scale mixing. This suggests that deformation took place while the sediment was unconsolidated.

This lithologic association occurs in scattered exposures

Figure 3.11: Laminated lithology; sandstone-rich
(upper Okuku River).

Figure 3.12: Laminated lithology; laminae of very fine
sandstone within silty mudstone.



Figure 3.13: Polished slab laminated lithology. Note disruption by small scale faults (small arrows) and sandstone injection (large arrow).

Figure 3.14: Laminated lithology, slightly disrupted by small scale faults.

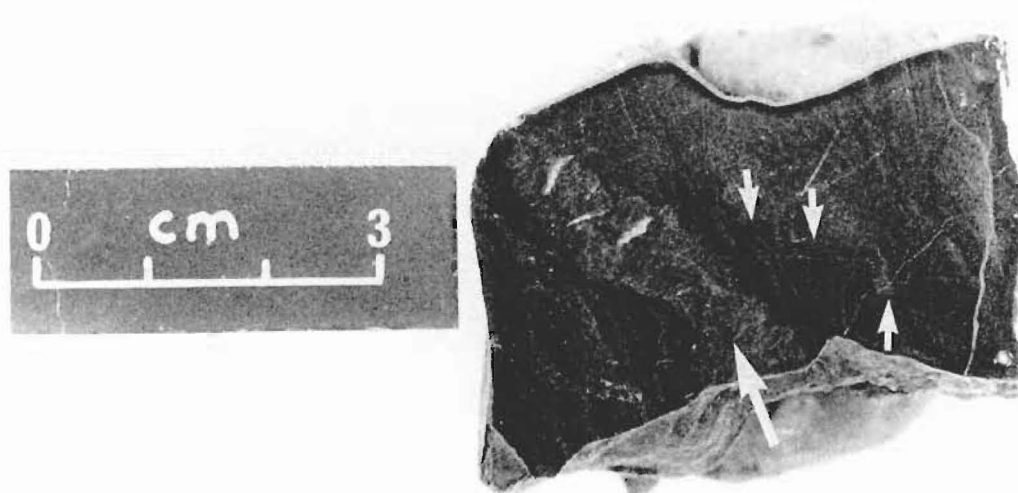
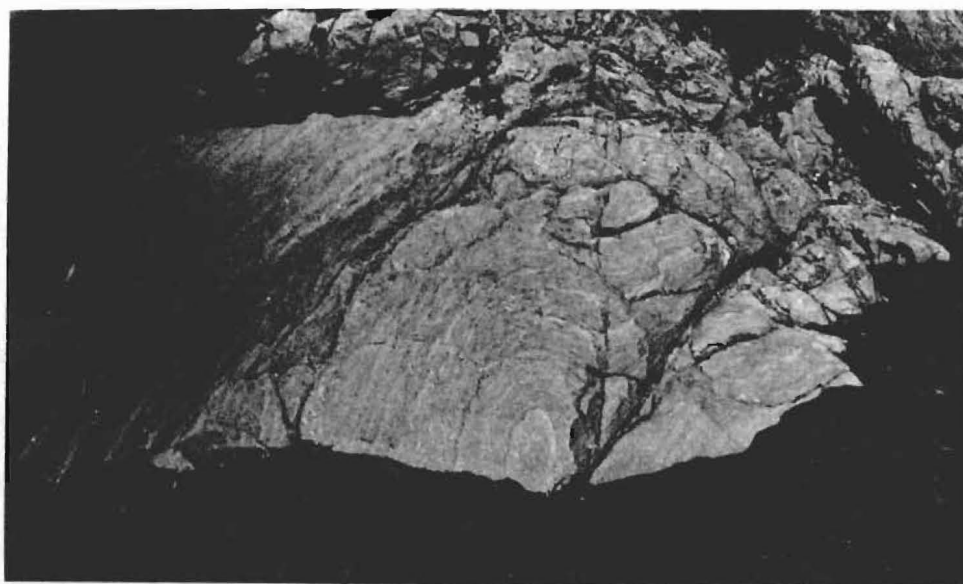


Figure 3.15: Clast of coarse sandstone within laminated lithology.

Figure 3.16: Soft sediment folding within laminated lithology (field of view approximately 2 m).



throughout the study area, but most notably in the eastern regions of the *mélange* zone (see geologic maps). The best exposure of laminated sediment occurs in the Okuku River (caM33/534 017) where it is associated with polymict conglomerate and is (somewhat atypically) sandstone dominated. In other occurrences, (e.g. Okuku River M34/550 993, M34/553 967) exposures range from 5 to 15 m in thickness and the laminated lithology is associated with *mélange* matrix lithologic associations described below.

3.3 MÉLANGE MATRIX ASSOCIATIONS

Mélange matrix associations are distinguished on the basis of observed field relationships and aspects of fabric noted in a study of slabbed samples and thin sections. The three associations recognized here are similar in that they frequently display high percentages of dark mudstone and a block and matrix character. They differ in details of fabric and inferred mode of formation.

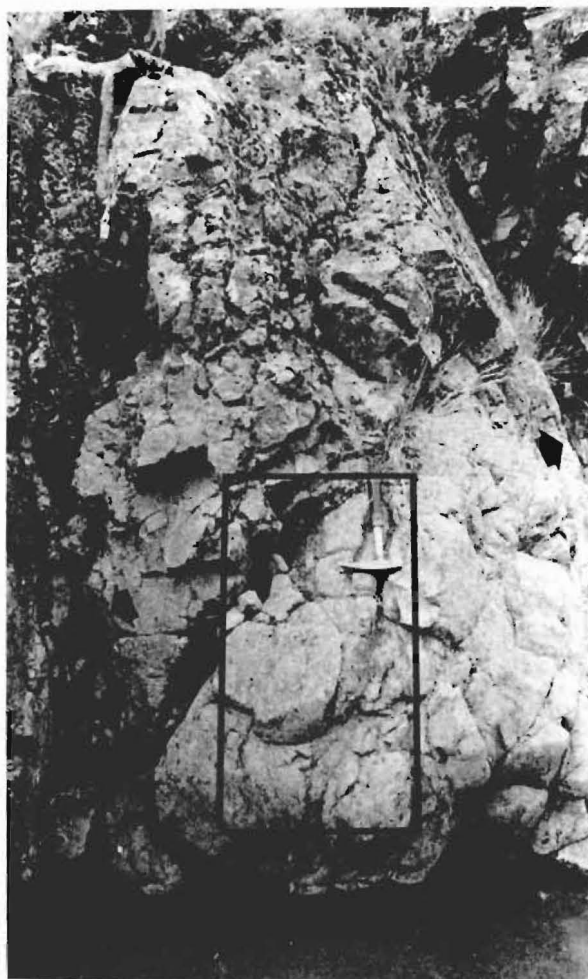
3.3.1 Bedded breccia association

As the name suggests, this lithology consists of bedded elements of brecciated or disrupted sandstone. Beds are commonly 1 to 3 m in thickness, however they are frequently disrupted and boudinaged. Beds are composed of pebble-size clasts of grey medium sandstone. The boundaries of these clasts may be well defined (figure 3.17) but are commonly very diffuse, giving the rock a peculiar mottled, disrupted appearance. In polished slab and thin section this effect appears to be due to a group of features which range from diffuse, well healed early or soft sediment faults to discrete, later stage fractures (figure 3.18).

Beds or blocks of "brecciated" sandstone occur within a variable matrix. The matrix is generally mudstone dominated and frequently

Figure 3.17a): "Bedded breccia", arrows indicate approximate margins of breccia bed. Block indicates location of detailed view (below).

b): "Bedded breccia", detailed view from above scene.



contains ragged clasts of sandstone which appear to have deformed as soft sediment (figure 3.19). Locally this matrix becomes very fine sandstone and contains sparse abraded granule to pebble size clasts of medium sandstone (figure 3.20). Sandstone blocks frequently display ragged margins where existing fracture sets seem to have been exploited in the donation of clasts to the matrix (figure 3.21). Invasion of matrix along fractures or between boudins is common (figure 3.22).

The bedded breccia association is noted predominantly in the eastern region of the *mélange* zone (within the Okuku study area) where it is part of sequences illustrated in figure 3.36. It appears to comprise many of the metre size blocks and larger rafts in the vicinity of L33/548 022 on the Okuku River. Near Glenard hut, in the vicinity of M34/544 988, several 2 to 5 m units of the bedded breccia are found related to, generally overlying, the "disorganized association" described below. Downstream, at M34/553 967 a several metre unit of bedded breccia is contained within a sequence dominated by the laminated lithology (figure 3.23). An isolated metre scale block of bedded breccia is noted in *mélange* in the Okuku River at M34/577 943.

3.3.2 "Disorganized" association

The disorganized *mélange* matrix association is characterized by angular pebble to boulder size "blocks" within variable percentages of a dark muddy matrix. The lithology generally displays no fabric on a hand specimen scale (figure 3.24) and an overall poorly developed fabric in outcrop (figure 3.25). Smaller clasts locally sweep around angular boulders (figure 3.26). Clasts are composed dominantly of grey fine to medium sandstone, but clasts of 1) mudstone, 2) the laminated lithology described above and locally tan weathering micritic limestone are also noted.

Figure 3.18: Polished slab, "bedded breccia" lithology. Note variety of fractured clast margins (dark clast is highly veined carbonaceous material).

Figure 3.19: Ragged clasts of sandstone within bedded breccia matrix.

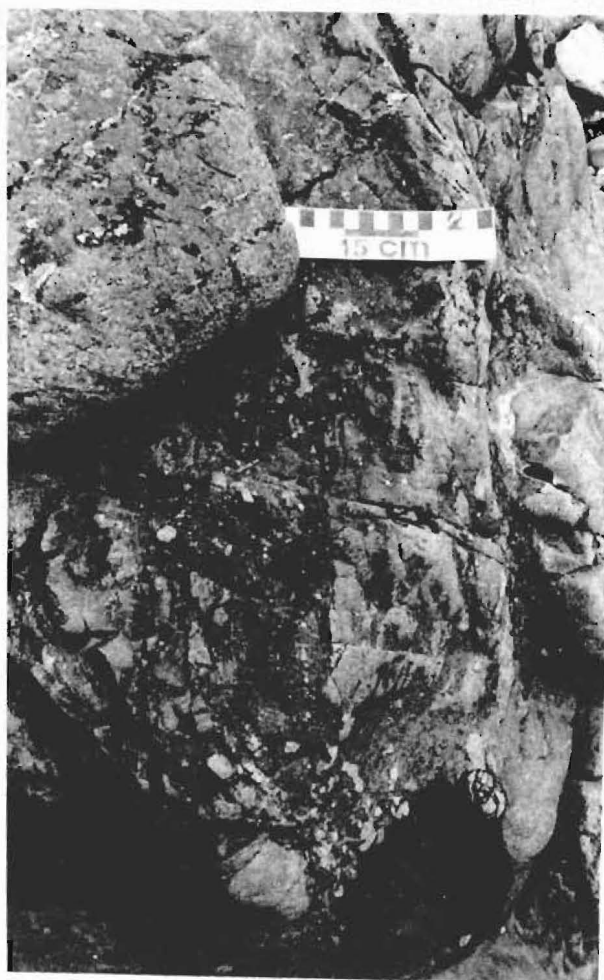
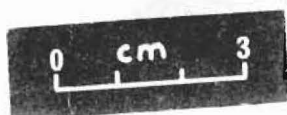
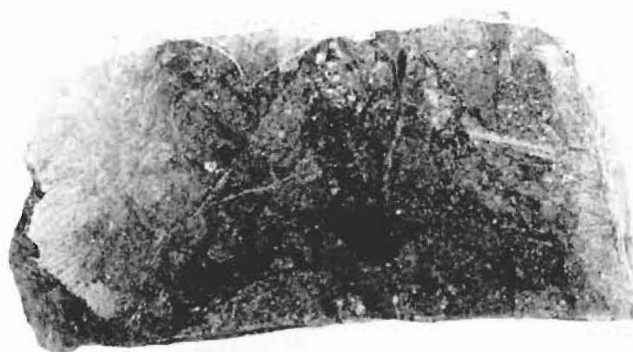


Figure 3.20: Bedded breccia matrix: fine sandy matrix with scattered granules to pebbles of "abraded" sandstone (small arrows).

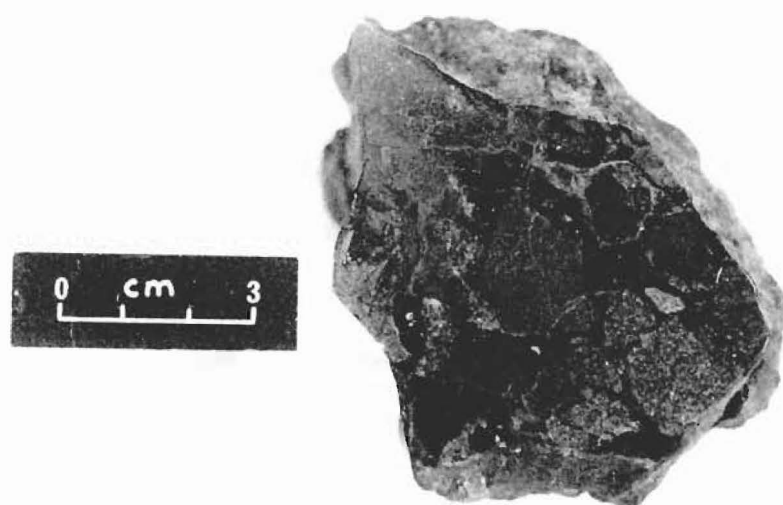
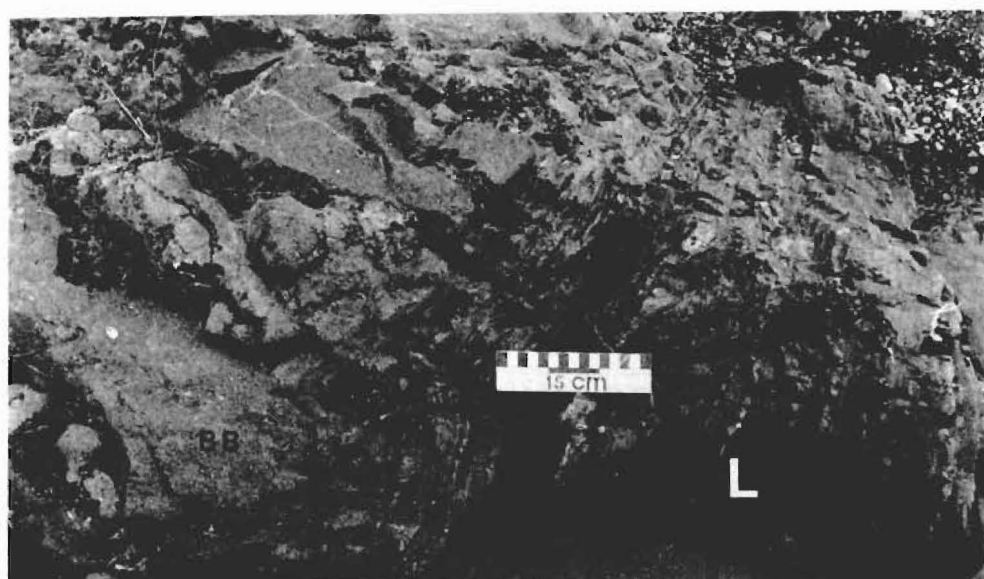
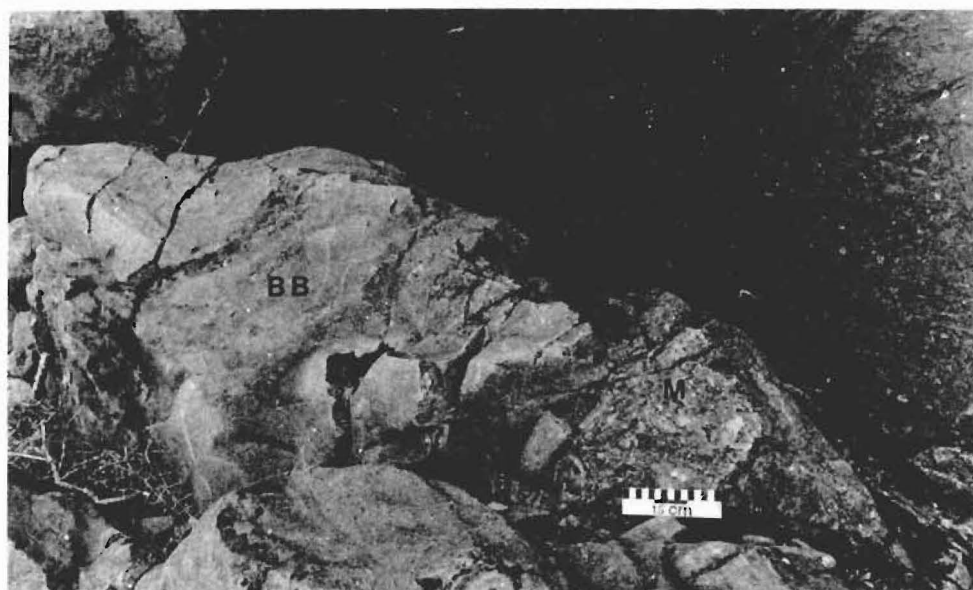
Figure 3.21: Bedded breccia association: ragged "block" margin denoting smaller "blocks" to matrix along pre-existing soft sediment fracture set.



Figure 3.22: Bedded breccia association: invasion of matrix (M) into fracture in bedded breccia unit (BB).

Figure 3.23: Contact between bedded breccia unit (BB) and laminated lithology (L).

Figure 3.24: Polished slab, "disorganized association". Note angular clasts and lack of fabric.



This association appears to occur as part of larger scale sequences in the eastern region of the *mélange* zone (exposed in several localities along the Okuku River). The disorganized lithology is noted on the Okuku River at M33/562 012 where it is approximately 5 m in thickness and appears to occur in the upper part of a polymict conglomerate and soft sediment deformed sequences. Here it is overlain to the southwest by a bedded breccia sequence. Near Glenard hut (M34/552 989), a 5 m unit of disorganized lithology appears to overlie a (convolute) laminated sequence. The appearance of this sequence seems to be accompanied by an angular discordance of fabrics (see geologic map). This may conceivably 1) be due to an unconformable relationship with rocks immediately to the north, 2) may reflect large scale rotated block-matrix relationships or 3) may represent some kind of folding. The last possibility is considered unlikely. Immediately downstream (M34/554 988) and possibly related to this sequence, the disorganized lithology is associated (or perhaps interbedded) with the bedded breccia lithology described above, in units approximately 2 to 5 m in thickness. Further downstream on the Okuku River (M34/556 974) the disorganized lithology appears as 15 cm to 1 m lenses within the laminated lithology (figure 3.27). Immediately to the south, it occurs as 1 to 2 m zones interstitial to, or containing, several metre-thick blocks of sandstone.

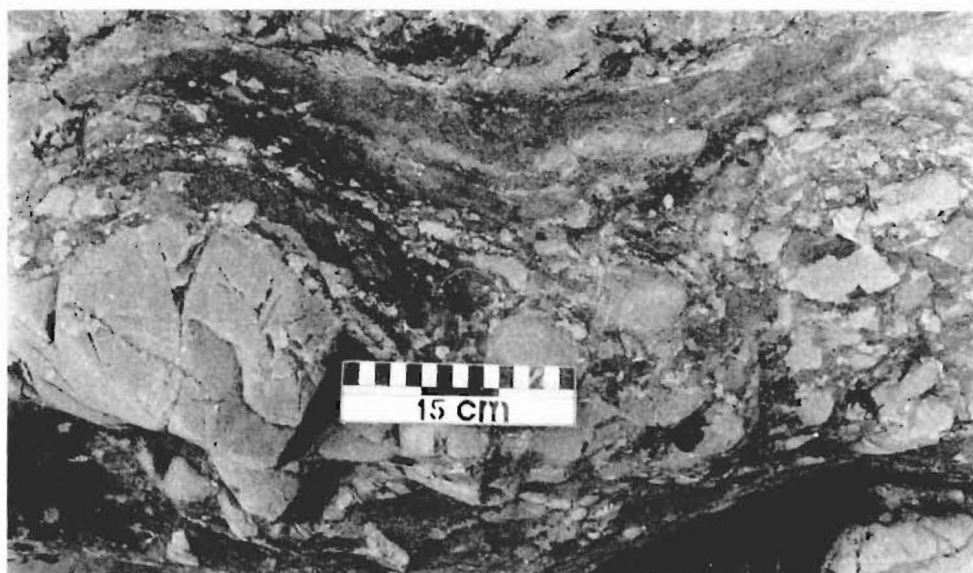
3.3.3 Blocky to laminar association

"Blocky to laminar" is a general name for the *mélange* matrix association which dominates, by volume, in the Esk Head *Mélange*. Overall the association is characterized by "blocks" or lozenges of sandstone or siltstone and locally metavolcanic, limestone, chert, or conglomerate floating in a dark mudstone matrix. The matrix commonly displays an irregular cleavage and a planar fabric is defined by the combination of this cleavage and the alignment of elongate "blocks".

Figure 3.25: Disorganized association. Note poorly developed fabric.

Figure 3.26: Disorganized association: local fabric defined by smaller "blocks" sweeping around larger one.

Figure 3.27: Thin lens of "disorganized" lithology within laminated association.



As mentioned in chapter 1, because the *mélange* displays a block and matrix texture on all scales, the distinction between a matrix association and included "blocks" becomes arbitrary. In the ensuing discussion, reference is generally made to a matrix association which contains "blocks" ranging in size from granules to cobbles or small boulders (Wentworth size classes). This is a loose distinction, of convenience in discussing features seen in outcrop or in polished slab. On the other hand, in terms of a map presentation, scale becomes the determining factor. Blocks which are too small to be mapped on the scale of 1:15,000 are considered part of the undifferentiated blocky matrix.

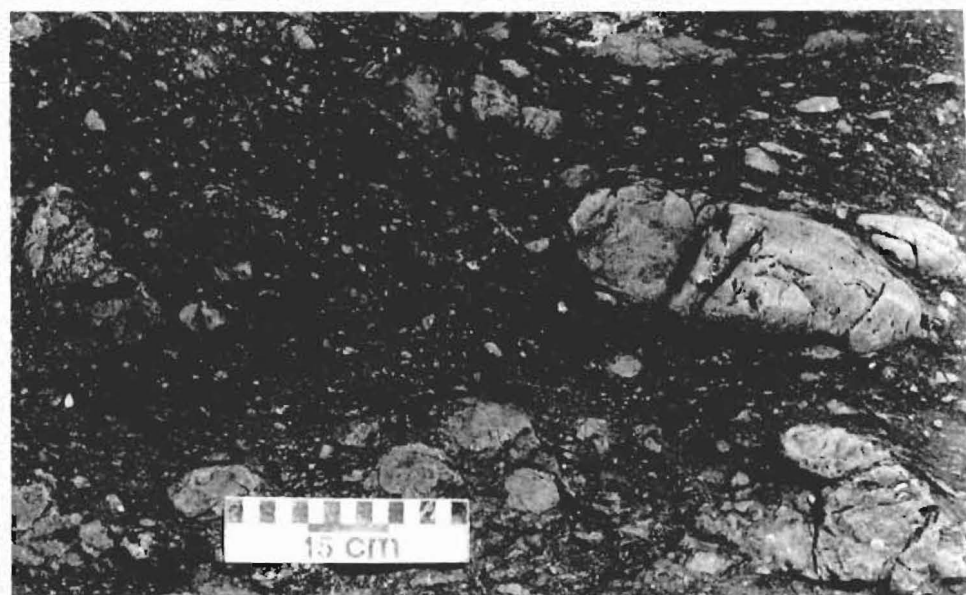
The blocky/laminar association includes a variety of lithologies which are closely associated. These grade into one another so frequently and over such short distances that they cannot be sensibly separated or mapped. The "blocky" end member of these lithologies is characterized by subsequent to elongate blocks, which are commonly rectangular or lozenge shaped in section and display well defined margins. The two opposing and parallel planar faces commonly observed at right angles to the dominant fabric are strongly suggestive of boudinage-related extension fractures. (figure 3.28). Blocks are generally well aligned and parallel to the cleavage of the mudstone matrix and as such define a measurable fabric. Blocks dominantly display a blade to disc shape, observable when they can be extracted from the matrix.

Zones dominated by rounded blocks are also noted (figure 3.29). A more chaotic orientation of blocks commonly accompanies this rounding, which appears to be a "plucking" effect.

The laminar end member is dominated by highly elongate, often wispy, sandstone or siltstone bodies within a dark matrix (figure 3.30).

Figure 3.28: Blocky *mélange* matrix: isolated "blocks" floating in a cleaved mudstone matrix. Arrows indicate orthogonal margins suggestive of boudinage origin.

Figure 3.29: Rounded mode of blocky *mélange* matrix: rounding is believed to be related to plucking of grains from "block" margins.



Deformation takes on the appearance of "laminar flow" and the outcrop locally displays a "banded" aspect. The contrasting appearance of the "blocky" and "laminar" end members in polished slab is illustrated in figure 3.31. All three modes (blocky, rounded and laminar) may be present in an outcrop (figure 3.32) and intermediate members exist among these and members. "Blocks" may display elongate "goatees" of sandstone or siltstone, related to later flattening (see chapter 5 - Structure).

Interpretation:

The origin of the blocky/laminar matrix association is uncertain, but field evidence suggests that it is produced, at least in part, by tectonic disruption of bedded units. In several areas, the association appears to be transitional through broken formation to bedded sandstone/mudstone intervals (figure 3.33). Structures observed at such localities suggest that clasts were produced by processes of 1) boudinage and 2) disruptive shearing of beds. The origin of isolated clasts in a matrix and the origin of the *mélange* fabric will be treated in more detail in chapter 5 - Structure.

While the blocky/laminar association appears to have been produced by tectonic effects, the variability of style displayed suggests that sediment may have been in various stages of lithification when disrupted. Creation of discrete blocks with well defined margins must have been achieved in at least moderately lithified sediment capable of sustaining extension and shear fracturing. Laminar styles, however, suggest a much lower competence difference between sandstone/siltstone and the surrounding mudstone. This may suggest deformation during earlier stages of lithification. Some measure of this difference is suggested in figure 3.34. This is a unique locality where a well rounded, completely undeformed calcareous boulder (concretion) is contained within a matrix association

Figure 3.30: "Laminar" end member of blocky/laminar mélange matrix in outcrop.

Figure 3.31a) and b): Comparison, in polished slab, between blocky (a) and laminar (b) mélange matrix.

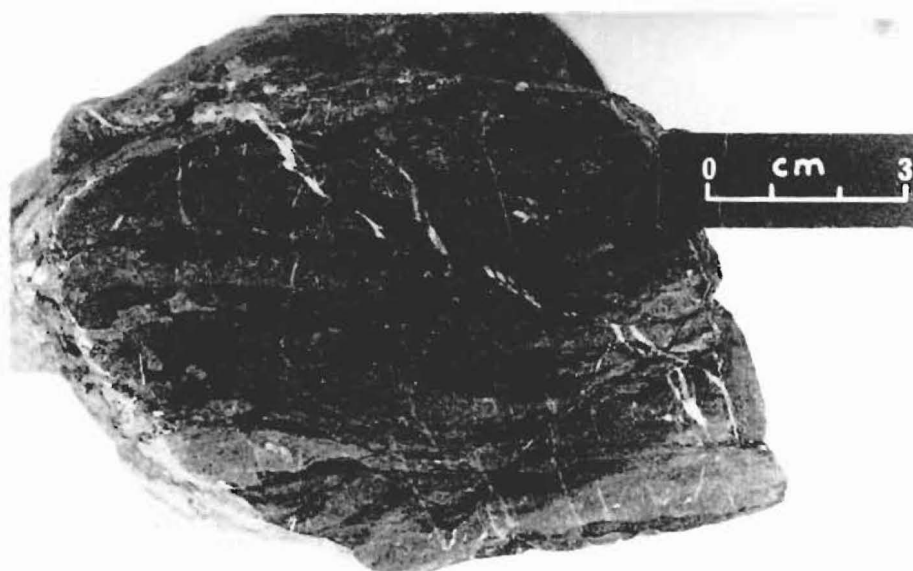
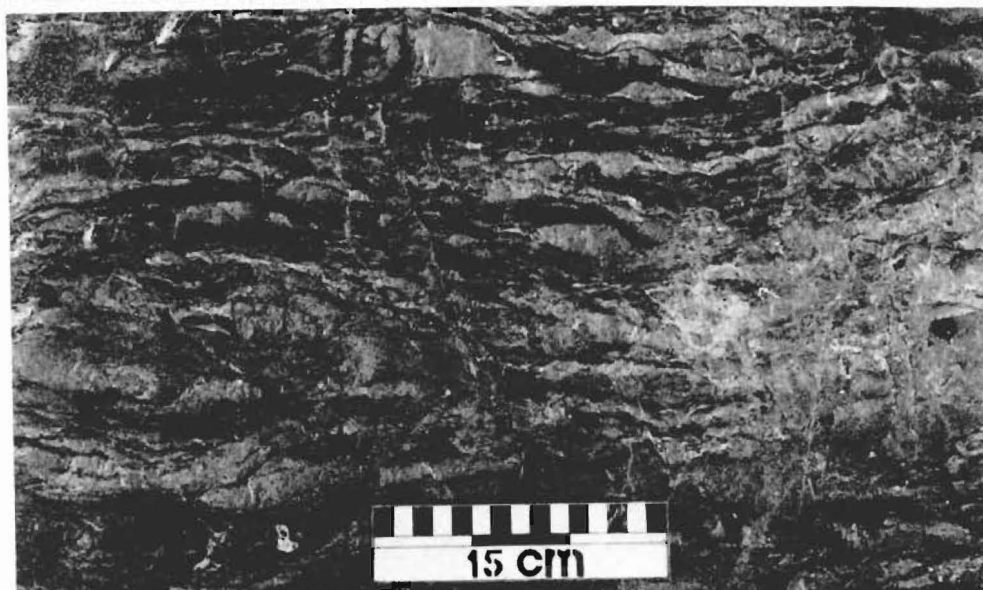
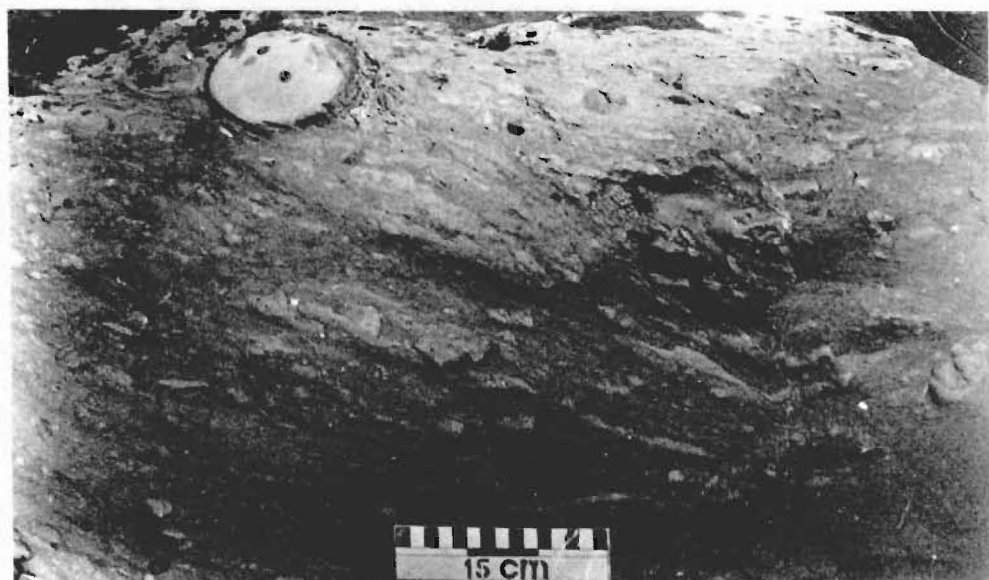


Figure 3.32: Mélange matrix: mixed blocky/laminar exposure.

Figure 3.33: Transitional contact between broken formation (BF) and mélange matrix (M). Minor fault is present near transition but offset is negligible.

Figure 3.34: Undeformed calcareous boulder within blocky/laminar mélange matrix.



displaying some "laminar-style" deformation. Foliations sweep around the boulder, suggesting that it is not simply a concentration which developed after deformation.

3.4 SYNTHESIS AND DISCUSSION OF LARGE SCALE SEQUENCES

Notwithstanding the widespread tectonic disruption and dislocation evident within the study area, several lithologies discussed in this section are seen to be strongly associated in four main areas. These areas define sequences which are different than the "block and matrix" character of the mélange zone as a whole. The emplacement of components by gravity-related processes is suggested.

The moderate to poor sorting, variable matrix, mixed angular and rounded clasts, lack of imbrication, vague platy fabric and locally channelized base suggest that the polymict conglomerates may represent debris flow deposits. The frequent occurrence of well rounded clasts as a component of these conglomerates suggests that they were derived, in part, from a high energy, shallow water environment which was responsible for the rounding. It should be noted that the composition of the conglomerates reflects all of the lithologies within the mélange zone as a whole. While conglomerates are generally dominated by sandstone, key minor components are limestone, metavolcanic and chert pebbles and cobbles. This aspect will be further discussed in the final chapter.

The laminated lithologic association is postulated to represent deep water background sedimentation which occurred around the time of emplacement of other lithologies. The "welded" contact with conglomerates in the vicinity of M33/534 017 suggests that deposition proceeded in this area immediately after debris flow emplacement. The soft sediment

folding and faulting within the laminated lithology may represent the effect of slumping. Isolated clasts may represent "rockfall" from upslope or may be precursors of arriving (gravity-emplaced) units.

The origin of the bedded breccia association is not clear. Brecciation is achieved by a spectrum of features ranging from diffuse soft sediment faults to discrete fractures. Overall the lithology presents a bedded aspect within a muddy to sandy matrix. Perhaps these features resulted during the downslope movement of poorly lithified, water-saturated sandstone beds. These may conceivably have begun to dewater along early fractures during movement, resulting in the varied style of brecciation observed. The suggestion has been advanced that this lithology represents sedimentary injections of some type (D.W. Lewis, pers.comm., 1982). The fact that a crosscutting relationship is never observed, the generally bedded nature of the unit and local transitional contacts with other lithologies, tend to militate against this however. The "disorganized" association is characterized by angular clasts of sandstone and siltstone in a disorganized fabric. This includes a widespread minor occurrence of clasts apparently derived from laminated lithology described above. This, the variability of the matrix and the apparently interbedded occurrence of this lithology suggest that it may represent thin, localized debris flow deposits which commonly overlie and have locally eroded the laminated association.

The blocky/laminar association as a group includes the vast majority of *mélange* matrix examined across the Esk Head *Mélange*. It is regarded as the product of tectonic rupturing and mixing of lithologies. This does not preclude the effect of shearing at the base of large rafts of sediment emplaced by gravity sliding down a slope. This effect, however, cannot be demonstrated nor clearly distinguished from other shearing

within the study area. Style of deformation in this case should vary with degree of lithification and proximity to the shear zone (basal shear zone in the case of sliding blocks). Figure 3.35 represents a schematic summary of the processes envisaged above. Table 3.1 also summarizes the lithologies of this chapter.

The four main sections linking these lithologies are shown in figure 3.36 a, b, c, and d. (For location see 1:50,000 geologic map.) Sections a) and b) occur on two subparallel limbs of the Okuku River, separated by a late stage sinistral fault which actually displaces the margin of the *mélange* zone. Although not directly correlatable in detail, the two sections are similar and are believed to represent the same sequence.

The three sequences figured record the emplacement and disruption of units by the subaqueous, gravity-related processes of sliding, slumping and debris flow. As such, they are regarded as "olistostromal sequences" (Flores, 1955; Abbate et al., 1970; Hoedemacker, 1973). They range in thickness from approximately 75 m (d) to roughly 1 km (a and b).

Mutti and Ricci Lucchi (1972) point out that very large submarine slides, as thick as hundreds of metres, may be intercalated in the normal deposits of the submarine fan facies association. There is a possibility that the sequences described above are such deposits, albeit with a strong tectonic overprint. However, I do not believe this to be the case. The unique lithologies and deformation styles noted, the overall thickness up to 1 km and the presence of lithologies completely exotic to the submarine fan environment (limestone, meta-volcanic and chert) all suggest that these sequences are not related to

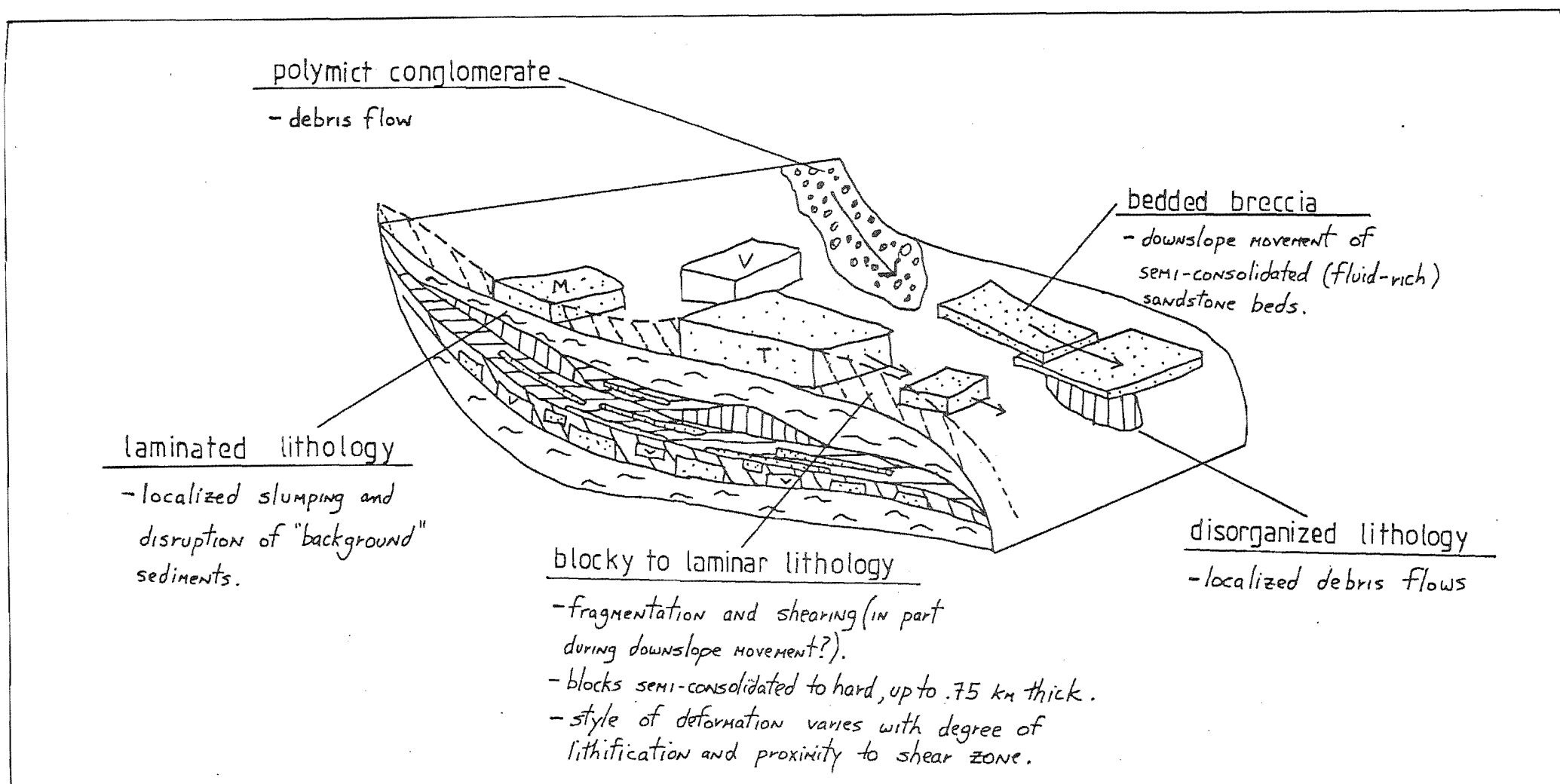


Figure 3.35: Schematic summary: postulated origin of olistostrome-related lithologies.

Table 3.1. Summary of Rock Types Characteristic of the Esk Head Mélange

Lithology	Characteristics	Postulated Origin
Polymict conglomerate	pebble to boulder conglomerate, moderately to poorly sorted, rounded to angular clasts; variable sandy to muddy matrix; vague platy fabric locally; beds 2 to 50 m (plus thin lenses locally); unconformable or scoured base; passes transitionally upward into blocky mélange matrix or overlain by laminated lithology in "welded" contact; contains clasts of sandstone, mudstone, volcanics, limestone and chert.	Debris flow
Laminated lithology	laminated siltstone (sandstone) and mudstone; laminae 2 to 10 mm thick; laminae commonly disrupted by soft sediment folding and faulting; locally cut by small scale sandstone injections; locally contains isolated clasts of coarse sandstone/conglomerate; overlies polymict conglomerate in "welded" contact and associated with "bedded breccia" and "disorganized" lithologies; beds commonly 5 to 15 m thick.	Deep water "background" sedimentation; disruption by slumping or arrival of gravity-emplaced units.
Bedded breccia lithology	bedded sandstone, "brecciated" into pebble-size clasts by soft sediment faults to discrete fractures; beds commonly 1 to 3 m thick; beds occur within variable muddy matrix containing ragged sandstone clasts; commonly associated with disorganized or laminated lithologies.	Downslope movement of poorly lithified, water-saturated sandstone beds.
Disorganized lithology	conglomerate composed of angular pebble to boulder size clasts within variable percentages of dark muddy matrix; poorly developed fabric; contains clasts of sandstone, mudstone, laminated lithology and limestone; beds up to 5 m thick; interbedded with or overlying laminated lithology and locally associated with bedded breccia.	Localized debris flow
Blocky/laminar lithology	"blocks" of sandstone/siltstone plus volcanics, limestone, chert, or conglomerate floating in a dark mudstone matrix; blocks vary from orthagonal to rounded to elongate and wispy in shape; cleavage in matrix and alignment of blocks defines a platy fabric; dominant lithology of the mélange zone.	Tectonic fragmentation and mixing of lithologies; possibly related to gravity sliding locally

submarine fan sedimentation in a simple way.

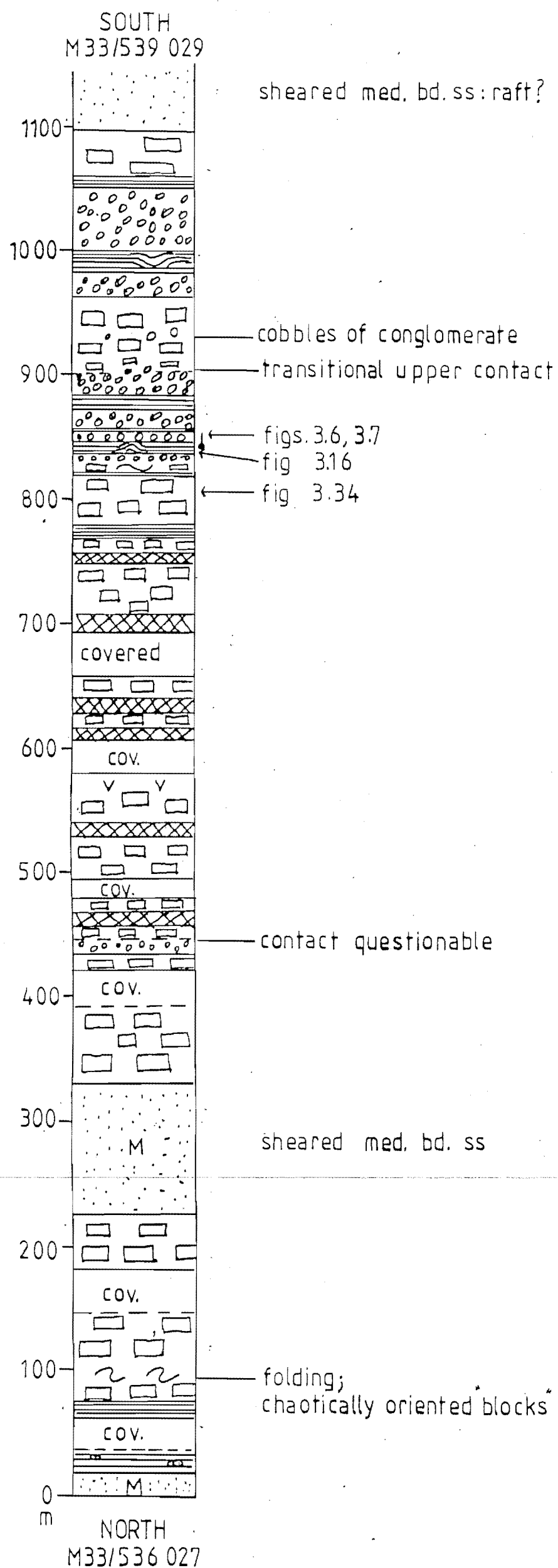
The contrasting style of disruption and deformation within these sequences suggests that sediment in various stages of lithification was involved in the gravity-related emplacement. Chaotic soft-sediment small scale folding is noted within these sequences and slump-related folds are believed to be responsible for the local facing reversals noted in section b). However, evidence of truly plastic deformation is not widespread, and sandstones seem to have deformed in a largely semi-plastic manner.

The blocky/laminar intervals within these sequences may have originated in two very different ways. They may reflect later stage shear zones and be totally unrelated to the sequences within which they occur. On the other hand, they may be an intimate part of the sequence, possibly related to downslope movement as mentioned above. I suspect that both processes are responsible for the occurrence of this association in this area. In several cases the blocky/laminar lithology is closely related to the polymict conglomerate, which is the lithology with the clearest sedimentary origin. This occurs, for example, in the vicinity of M33/564 016. Here disruption is believed to be an early effect, related to downslope movement, and the blocky/laminar lithology is viewed as an integral part of the sequence. Considering the *mélange* as a whole, however, the widespread development of a block and matrix character appears to be related to larger scale tectonic deformation.

The three main sequences figured, plus other scattered occurrences of similar lithologies represent isolated "olistostromal sequences" separated by broad areas of blocky *mélange*. They are confined to the eastern regions of the *mélange* zone in the Okuku study area and similar

lithologies are noted only as smaller blocks within mélangé in the (south) western regions and in the whole of the Esk Head study area. The significance of this distribution will be discussed in the final chapter.

a) "UPSTREAM" sequence



b) "DOWNSTREAM" sequence

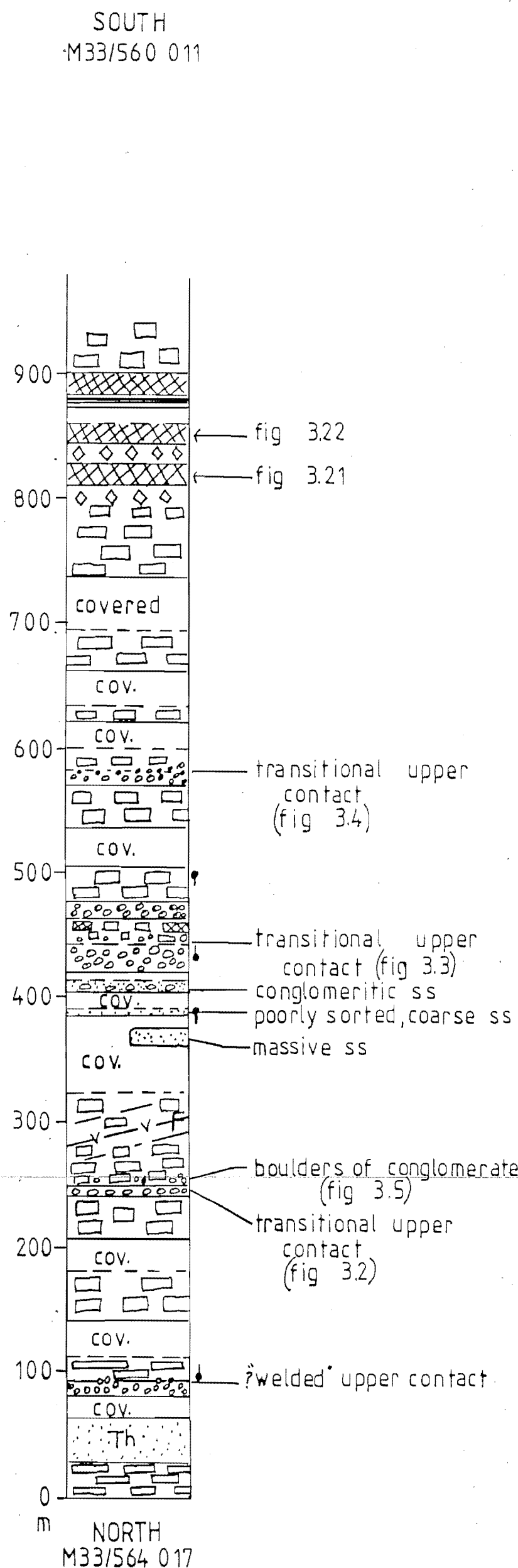
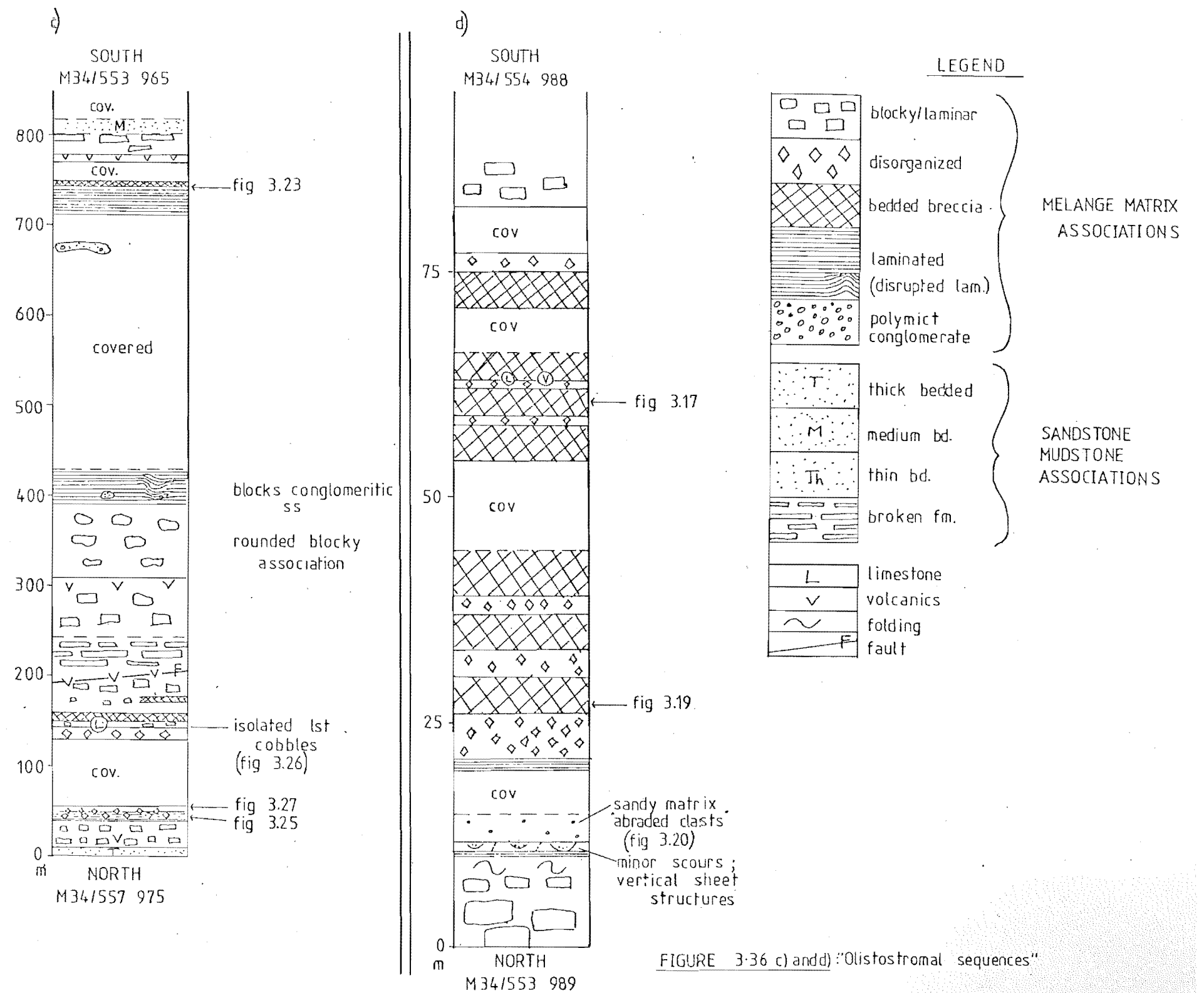


FIGURE 3.36 a) and b) : "Olistostromal sequences"



CHAPTER FOUR

METAMORPHISM

4.1 INTRODUCTION

Metamorphism is defined as "the mineralogic and structural adjustment of solid rocks to physical and chemical conditions which have been imposed at depths below the surface zones of weathering and cementation, and that differ from the conditions under which the rock in question originated" (Turner, 1981). This chapter is concerned with metamorphism in the sense of mineralogic changes or the growth of new minerals (including vein minerals) in the rocks of the Esk Head/Okuku area which are suggestive of the P-T conditions under which those rocks were deformed. The deformational effects recorded by the Esk Head M \acute{e} lange will be treated in chapter 5 - Structure.

Field evidence suggests that the rocks of the Esk Head/Okuku area have undergone only very low grade metamorphism. Sandstone lithologies are well indurated, but display no schistosity. New mineral growth is confined to veins, and to possible mineralogic changes in the mudstone matrix of the m \acute{e} lange. Areas of extensive white mineral veining are widespread. Veins are generally thin, commonly less than 0.5 mm and appear to be nonsystematic. Areas with abundant veining commonly display discrete margins and are juxtaposed with non-veined exposures in a manner which suggests "post-veining" minor fault displacement.

4.2 VEIN MINERALS

The metamorphic grade of various lithologies across the m \acute{e} lange zone was surveyed by examination of thin sections and grain mounts. A

total of 35 sandstone, 14 *mélange* matrix, 10 limestone, 8 volcanic and 3 chert thin sections, and 12 grain mounts were examined. In every case, the growth of diagnostic metamorphic minerals was noted within veins only. Possible mineralogic changes in the matrix will be discussed below. Many samples show only very minor quartz or calcite veins, or no veins at all, and are regarded as essentially unmetamorphased. No textures suggestive of retrograde metamorphism are noted.

4.2.1 Calcite and Quartz

The most widespread vein minerals seen are calcite and quartz. Crosscutting relationships suggest several episodes of veining. While considerable variation exists among samples, a general pattern of early calcite and quartz veining, followed by later calcite veining is observed. Patchy calcite replacement noted in some sandstone thin sections (see diagenesis of sandstones - chapter 2) may be related to calcite veining in some cases. The second episode of calcite veining may be related to the introduction of calcite-rich fluids along late-stage (Kaikoura) faults and fracture systems. A major late stage fault is mapped trending through the Stockyard Stream area (ca.M33/533 002). Here distinctive, hair-like, reddish calcite veinlets crosscut sandstone and mudstone lithologies, and a nearby (Late Cretaceous) dyke displays extensive calcite replacement. In the Middle Branch Waipara River, (M33/654 007) intersecting fracture sets display extensive calcite (and minor pyrite) filling up to 2 cm in thickness (figure 4.1). The dominant calcite filled fracture set here is oriented 075/80S, roughly parallel to major late-stage faulting.

The extensive chlorite and calcite alteration noted in volcanics generally (see chapter 2) is believed to be an early alteration effect and not directly related to the burial metamorphism suffered by the zone

Figure 4.1: Calcite filled fractures in sandstone,
Middle Branch Waipara River.

Figure 4.3: Possible P-T fields for low-grade mineral
facies and subfacies from Coombs (1971).

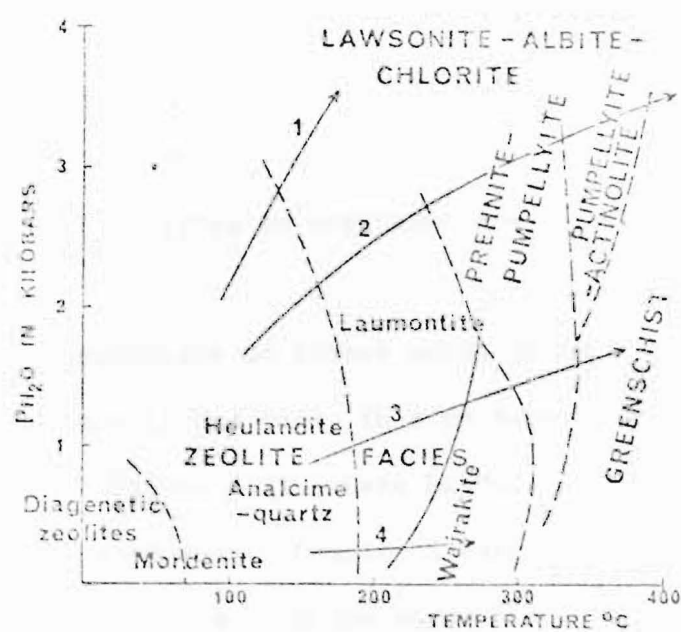


Figure 3. Possible P-T fields for low-grade mineral facies and subfacies, calibrated for the laumontite-wairakite and analcime + quartz-albite reactions (21, 3). Where $P_{H_2O} < P_{total}$, boundaries are displaced to the left. Arrows represent facies series as follows, slightly modified from Seki (35).

- (1) High pressure, low temperature
- (2) Intermediate
- (3) Low pressure intermediate
- (4) Lowest pressure

as a whole. Similarly, the extensive quartz veining seen in cherts is thought to be an early diagenetic effect (see chapter 2).

4.2.2 Zeolites (and prehnite)

Veins of quartz plus laumontite are noted in several thin sections and grain mounts. Laumontite is a distinctive zeolite, recognizable by its low relief, low birefringence and three distinct cleavages. Veins of laumontite up to 1 mm in thickness occur, locally cut by a later minor fracture set. In one case, a quartz plus laumontite vein is truncated by a fracture which accommodates an injection of siltstone. Here veining has predated the final stages of soft sediment deformation. In one sample from the Esk Head study area (sample E-3) laumontite appears to be acting, in part, as a cement within a unit of fine sandstone.

Zeolites (natrolite) also occur as amygdale fillings associated with chlorite in two volcanic samples: sample 45 from the Okuku River (M33/525 017) and sample 222 from above Lees Pass (M34/596 979). These two occurrences of zeolites in amygdales are regarded as diagenetic.

Minerals suggestive of higher grade metamorphism, i.e. prehnite, have been noted in only one case, in a tuffaceous volcanic sample (location shown in figure 4.2). Here bladed crystals of prehnite occur in a calcite-dominated vein. Despite a careful search, no pumpellyite was located in any samples from the study area.

The distribution of vein minerals seen in thin section and grain mounts is shown in figure 4.2.

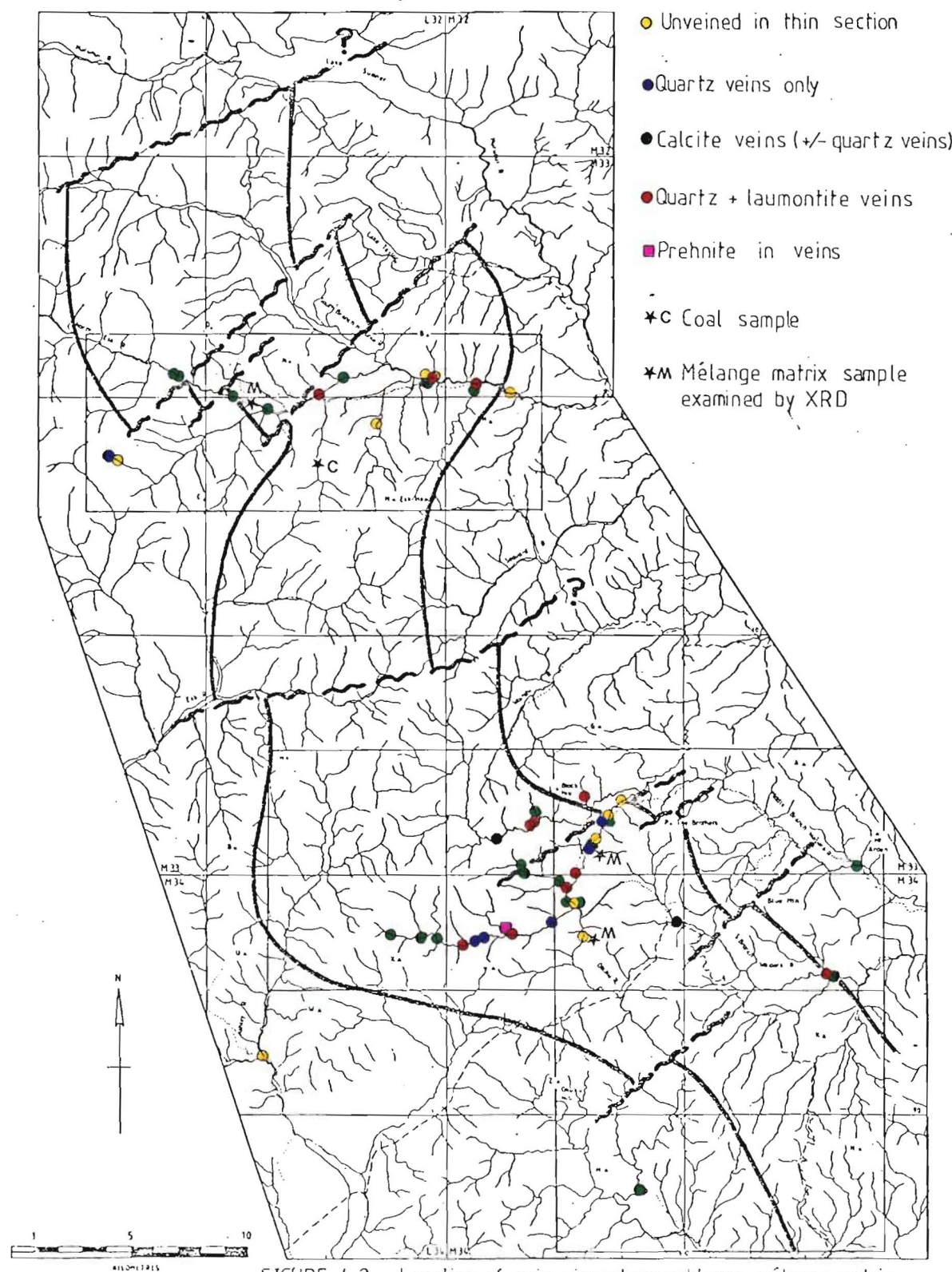


FIGURE 4.2: Location of vein mineral assemblages, mélange matrix and coal sample

4.2.3 Indicated metamorphic grade from vein minerals

With regard to the significance of vein minerals in establishing metamorphic grade, Coombs (1959, p.67) says "The metamorphic significance of a late stage zeolite or prehnite-bearing vein is that the rock it cuts has passed through a metamorphic maximum with P-T conditions at least as severe as those of which the vein mineral assemblage is diagnostic". In this case, the rocks of the study area are regarded as falling within the zeolite facies of metamorphism, which is described by Coombs (1971) as being characterized by the mineral assemblage calcium zeolite-chlorite-quartz (in rocks of favourable bulk composition). The relationship of low grade metamorphic facies is shown in figure 4.3. The notable absence of pumpellyite and single occurrence of prehnite in samples examined provides a reasonably clear upper limit for the metamorphic facies of these rocks. While albite was not noted as a vein mineral, the common occurrence of quartz plus laumontite veins suggests that the rocks of the Esk Head/Okuku area reached a metamorphic maximum within the laumontite-albite-quartz subfacies of the zeolite facies.

Coombs *et al* (1959) suggest that a laumontite-albite-quartz (-chlorite) assemblage may have formed at depths from 9 to 15 km and throughout this zone, especially at deeper levels, prehnite and pumpellyite may begin to replace laumontite. Boles and Coombs (1975) suggest that laumontite may form as a cement at temperatures as low as 50 to 100°C and may survive to maximum temperatures of 200 or even 300°C. They estimate a minimum temperature of pumpellyite formation as 190 to 200°C. It is important to note that within the zeolite facies, the simple controls of pressure and temperature may be over-ridden by the variable local effects of permeability, parent materials, incomplete reactions, ionic activity ratios, partial pressure of carbon dioxide, and fluid

pressure with respect to total pressure (Boles and Coombs, 1977).

Vein mineral assemblages may be particularly sensitive to ionic activity ratios and pore fluid pressure (Coombs, 1960). The isolated occurrence of prehnite in the volcanic sample, therefore, does not necessarily imply a higher metamorphic grade, but may well be an effect of local chemistry. Causes for the consistent occurrence of diagnostic metamorphic minerals as veins only in the rocks of the *mélange* zone, may be include: a) transient residence under favourable P-T conditions, 2) early low permeability, possibly related to rapid compaction or very fine grain size in detrital sediments.

4.2.4 Veins within *mélange* matrix

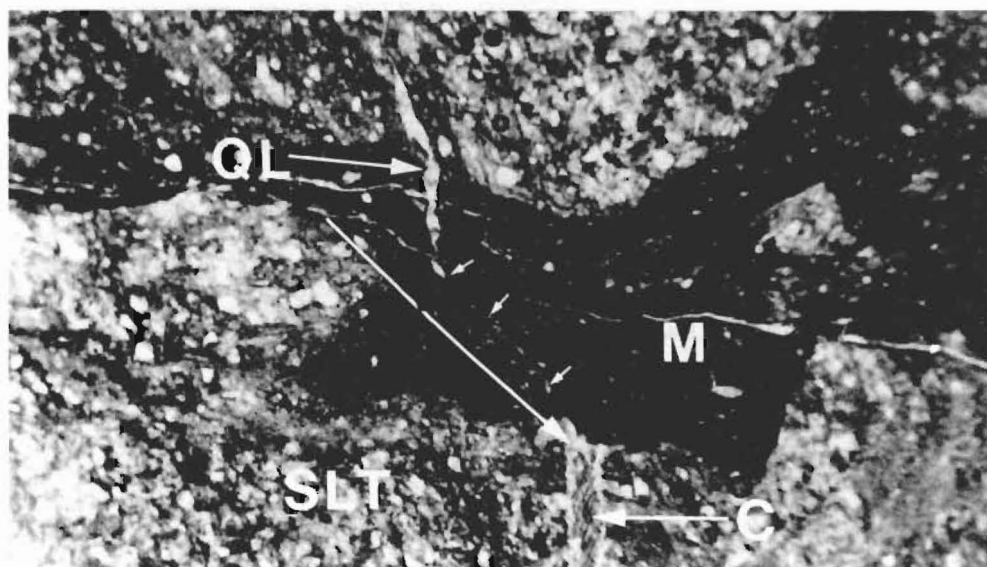
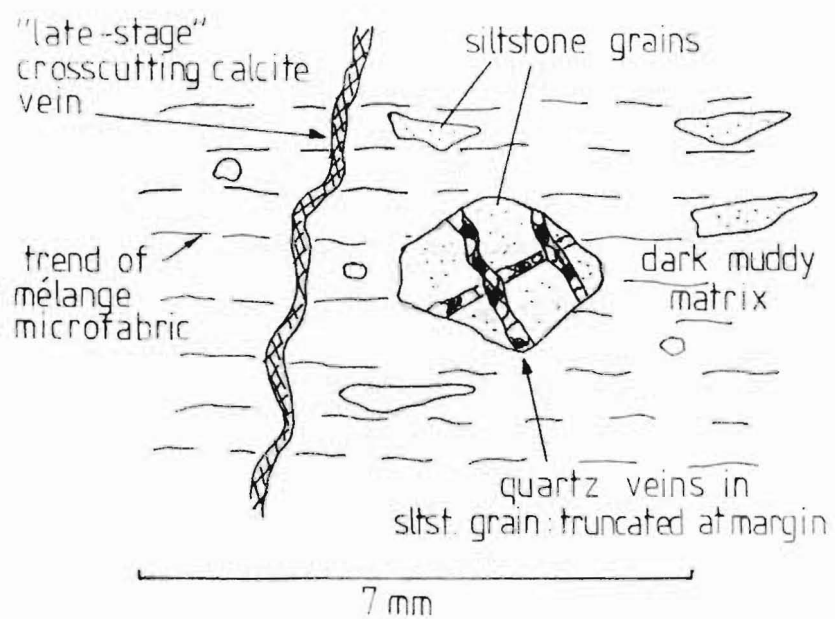
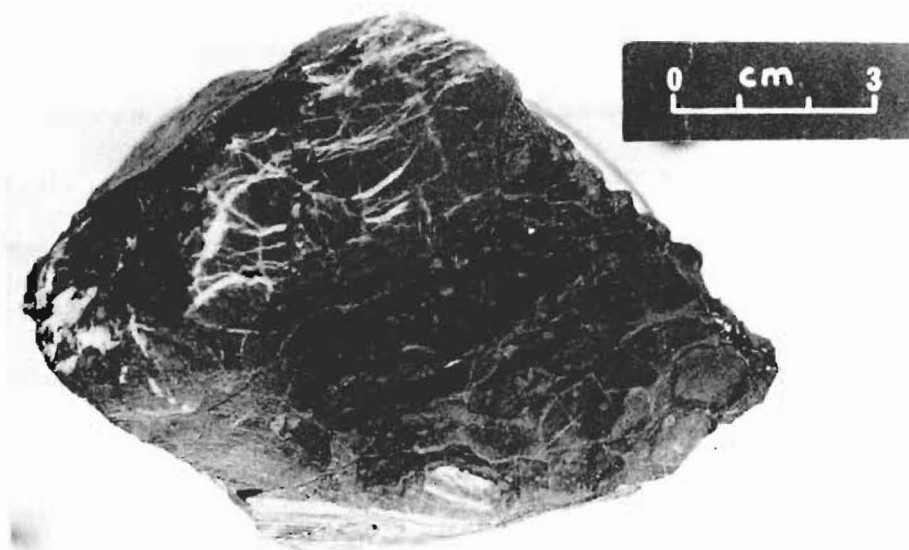
Veining is common within *mélange* matrix samples and can be seen in thin section and polished slab. Veining and calcite replacement are commonly confined to sandstone/siltstone "blocks" (figure 4.4). Viewed simply, this suggests that veining predates *mélange* formation, but detailed examination of many samples suggests that veining/*mélange* relationships are more complex. Veins, in fact, display a range of age relationships with the *mélange* process:

- 1) Some grains or clasts display veins which are truncated at the grain/matrix boundary and show no consistent relationship to the surrounding microfabric or nearby veins (figure 4.5). These are regarded as early, "pre-*mélange*" veins.
- 2) A second family of veins are commonly truncated or distinctly thinned at "block" (grain)/matrix boundaries. Several cases of attenuated veins extending across matrix are noted. Figure 4.6 illustrates such a case, where a quartz plus laumontite, (plus later calcite) vein is developed in siltstone grains but displays an attenuated trace across intervening matrix. Veinlets of quartz (plus laumontite) also appear within the matrix as microscopic "tension gashes" (figure 4.7) and

Figure 4.4: Blocky *mélange* matrix in polished slab showing confinement of calcite veining to "blocks". Calcite at left margin is an almost total replacement of siltstone "streamers".

Figure 4.5: Sketch from thin section: "early" quartz veins within siltstone grain, which are sharply truncated at grain margin and bear no obvious relationship to matrix microfabric or nearby veins.

Figure 4.6: *Mélange* matrix: attenuated quartz plus laumontite vein (QL) locally cored with calcite (C) well developed in siltstone "block" (SLT) and tracing across matrix (M). (Field of view approximately 3.4 mm)



extending along oblique minor shears. Veinlets are also seen to extend through siltstone grains and thence trace along the grain/matrix boundary (figure 4.8). Buckled quartz veinlets are also noted extending across the *mélange* microfabric at roughly right angles (figure 4.9). These are believed to have been present prior to a late-stage *mélange*-flattening event. (For further discussion see chapter 5 - Structure.) All of these features suggest that vein formation was an ongoing process during *mélange* formation.

3) Some vein sets, notably calcite, cut across the *mélange* fabric indiscriminantly and postdate *mélange* formation.

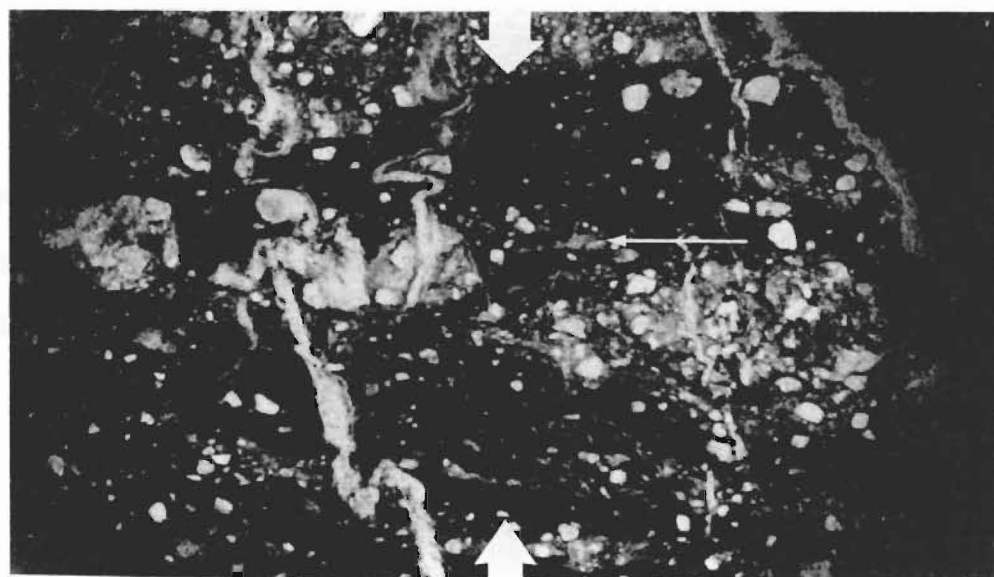
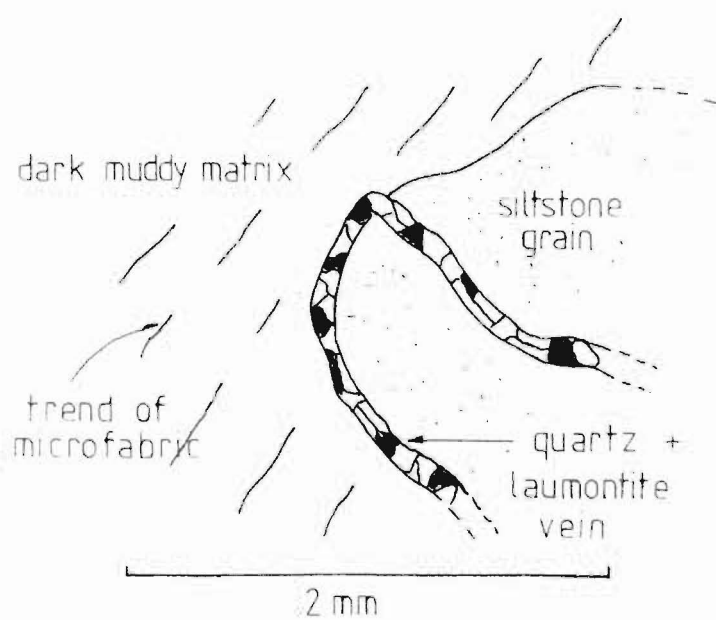
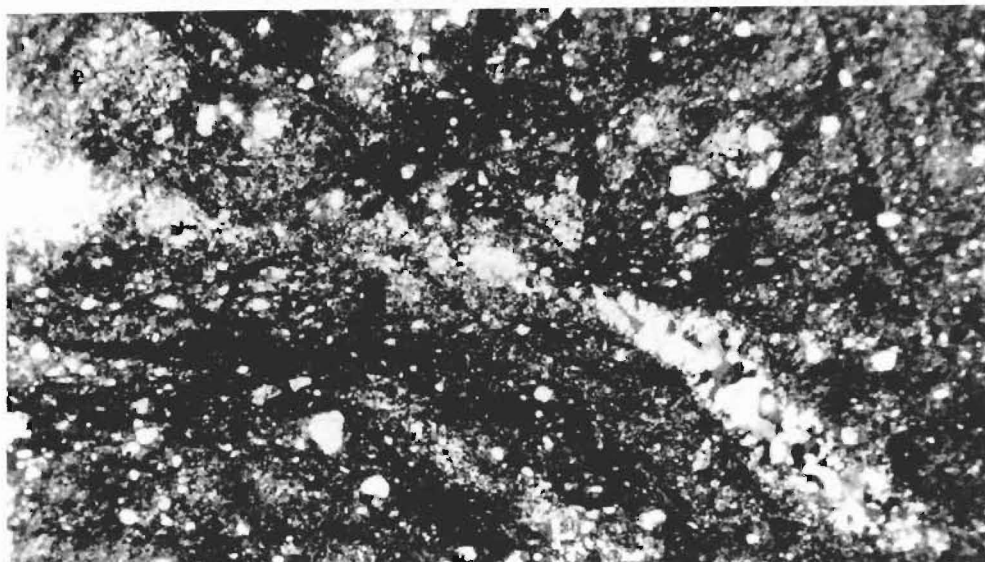
It appears that a spectrum of veins were emplaced around the time of *mélange* formation. A sequence noted in one sample is a) quartz veins, truncated by b) calcite veins which terminate at "block" margins, truncated by c) quartz plus laumontite veins which transect "block" margins and are locally cored or replaced by calcite. Stage "b)" calcite veins locally terminate at early healed microfractures, but this is believed to be a permeability barrier effect rather than a faulted truncation (figure 4.10). Calcite veinlets locally develop along, or intrude into, similar healed microfractures. More discrete, later micro-faults also displace veins within "blocks".

In summary it appears that vein emplacement occurred before, during and after *mélange* formation. The climax of metamorphic grade, in the form of quartz plus laumontite veins, appears to have occurred during *mélange* formation. Veining may have occurred as reactive fluid was injected along early-propagating fractures in sandstone/siltstone "blocks", during progressive deformation within a fluid-rich muddy matrix. The frequent confinement of veins to sandstone/siltstone "blocks" and grains (and converse rarity in matrix) appears to be related more to 1) the

Figure 4.7: Quartz-filled tension gashes (Q) in mélange matrix. Arrow roughly parallel to mélange matrix microfabric.
(Field of view approximately 3.4 mm)

Figure 4.8: Sketch from thin section: Quartz plus laumontite vein extending through siltstone grain and following grain/matrix boundary.

Figure 4.9: Buckled quartz veins within mélange matrix. Thick arrows indicate approximate axis of flattening. Thin arrow roughly parallel with mélange matrix microfabric.
(Field of view approximately 6.5 mm)



ductility contrast between "blocks" and matrix and 2) the favourable porosity, permeability and host mineralogy of these "blocks", than to timing. Metamorphism, manifested as veining, appears to have been an ongoing process during mélangé formation.

4.3 CLAY MINERALOGY OF THE MATRIX

In general, increasing burial metamorphism results in progressive changes in clay mineralogy viz. 1) the destruction of kaolinite, 2) the conversion of montmorillonite to illite and chlorite and 3) the increasing crystallinity of illite.

Kaolinite is regarded as a weathering product which is progressively destroyed during burial metamorphism. While the stability of kaolinite may vary with the geochemistry of pore fluids, the upper limit of kaolinite stability is believed to be roughly 200°C (de Segonac, 1970; Boles and Franks, 1979). The persistence of kaolinite to the total depth of a drillhole at 5000 m and 180°C has been described by Burst (1959, as cited in de Segonac, 1970). Frey (1970) notes the disappearance of kaolinite prior to the appearance of prehnite in a laumontite-free metamorphic sequence from the Swiss Alps.

The gradual conversion of montmorillonite to illite or chlorite takes place through intermediate mixed layers of illite/montmorillonite (I/M) (de Segonac, 1970). The montmorillonite to illite transition is a dehydration process which advances with increasing temperature and pressure. Muffler and White (1969) note the stability of the mixed layer clays between 80 and 200°C. The complete destruction of I/M layers at depths greater than 4,500 m was described by Burst, (1959, as summarized in de Segonac, 1970).

Illites are believed to be stable to 700°C (Carroll, 1970) but undergo a progressive increase in crystallinity through increasing metamorphism and form a continuous series with micas. This increase in crystallinity can be quantified through x-ray diffraction techniques, by measuring the width of illite 10 Å peak at half height (de Segonac, 1970).

Three samples of dark muddy *mélange* matrix were examined by x-ray diffraction. Samples represent blocky, laminar and disorganized *mélange* matrix associations (see chapter 3). Location of samples is shown in figure 4.2. The x-ray diffraction patterns for these three samples are virtually identical. An example is shown in figure 4.11. The matrix is composed of illite, chlorite and kaolinite. Montmorillonite or mixed layer clays are absent. The crystallinity index of illite appears very similar in all three samples. Detailed comparison of illite crystallinity in matrix samples from throughout the *mélange* zone might provide some insight into metamorphic history but this was considered beyond the scope of this project.

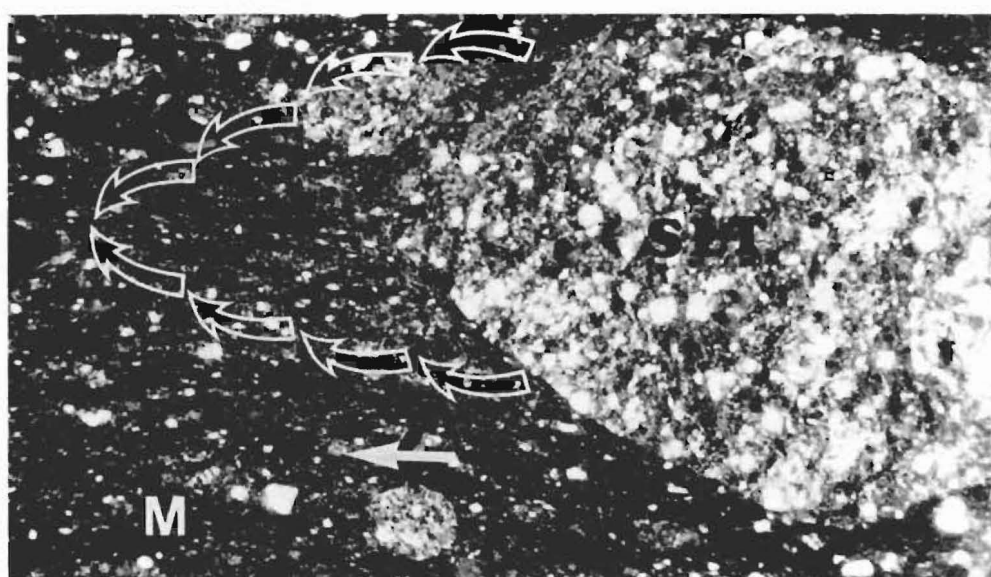
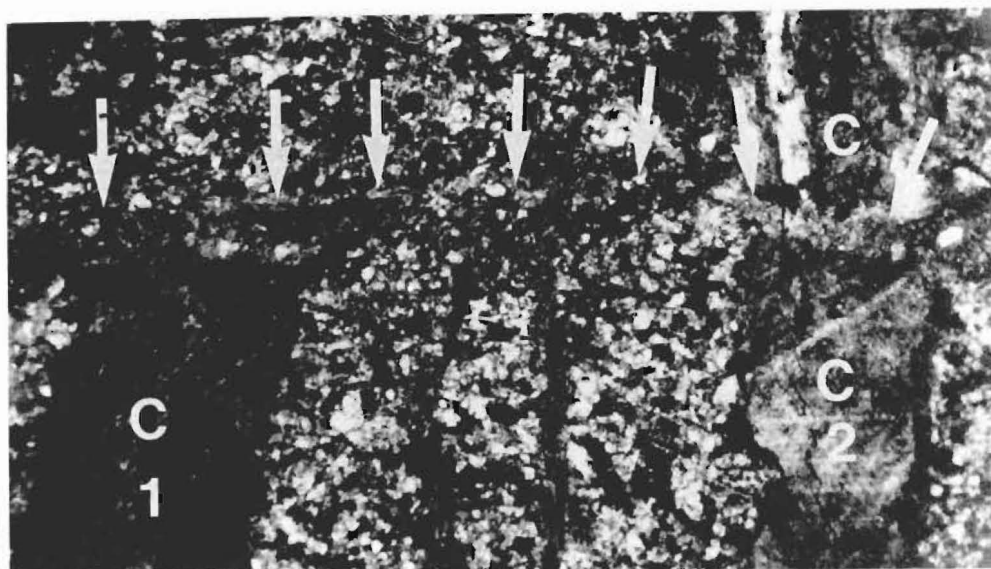
Considering the foregoing discussion of clay mineral stability, it appears that the matrix represented by these three samples has achieved temperatures close to, but not significantly exceeding 200°C. This appears compatible with the laumontite-albite-quartz grade of the zeolite facies established for vein minerals.

New mineral growth in the matrix:

A flattened fabric is noted in many areas of the Esk Head *Mélange*. "Strain shadows" or "goatees" extended from "blocks"/grains are noted both in outcrop and in thin section (see chapter 5 - Structure). In general, "strain shadows" are occupied by new mineral growth whereas "goatees" accommodate material plucked from surrounding competent grains,

Figure 4.10: Calcite veins (C) both truncated (1) and extending across (2) healed microfracture (indicated by series of arrows). (Field of view approximately 3.4 mm)

Figure 4.12: Crystallization of very fine crystalline sericite in the "strain shadow" of a siltstone grain. Rounded siltstone grain (SLT) within matrix (M). Arrow enclose zone of maximum recrystallization. Note "detached grain" separated from parent grain in upper part of "strain shadow". Solid arrow roughly parallel to mélange matrix microfabric. (Field of view approximately 3.4 mm)



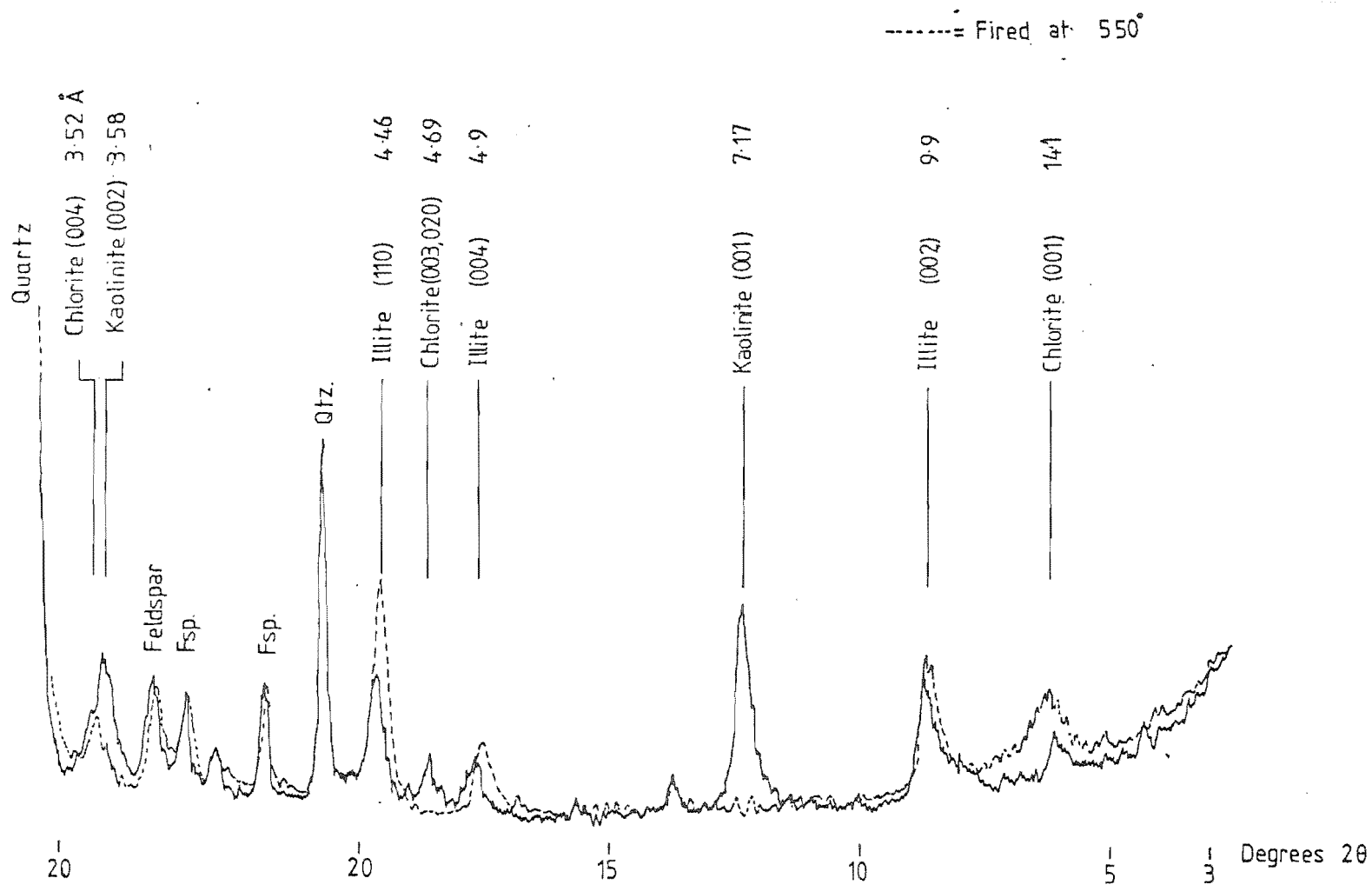


Figure 4.11: X-ray diffractogram of mélange matrix.

but every gradation exists between the two (Stauffer, 1967). Thin sections of mélangé matrix most commonly display "goatees" of rounded quartz, feldspar or rock fragment grains. In a few sections the growth of very fine crystalline sericite is observed to accompany this (see figure 4.12). This is believed to be a low grade metamorphic recrystallization of illite within the matrix, accompanying the flattening process. The mechanism of this recrystallization is uncertain.

4.4 COAL SAMPLE

An increase in coal rank parallels increasing burial metamorphic grade, although there is no absolute correlation and interpretation from different studies varies considerably. Increasing coal rank is indicated by increasing reflectance (R_m) and decreasing volatile matter (V.M.). The correlation of these two rank parameters is shown in figure 4.13. Kisch (1974; summarized in Turner, 1980) suggests that the general span of the zeolite facies in Paleozoic and Mesozoic coalfields corresponds to a range of rank from subbituminous to semianthracite. According to Kisch, the transition from the heulandite-analcite-quartz grade to the laumontite-albite-quartz grade occurs at ranks ranging from V.M.~39 in Cretaceous coals to V.M.~31 in Upper Carboniferous coals. A recent study (Kisch, 1981) indicates coal ranks ranging from R_m .60 to 1.33 in zeolite-facies rocks from the Southland Syncline.

Carbonaceous material is sparse within the study area and only one sample of adequate size for reflectance measurement was collected. This is an angular fragment of coal 1 x 1.5 cm found in isolated outcrop within massive sandstone in Deep Stream (L33/447 173) (see figure 4.2). The material is homogeneous and probably derived from a single piece of wood. Cell structure is indistinct and pyrite is present. Measured reflectance is 0.73% (J. Newman, pers.comm., 1982). This reflectance corresponds to

Rank		Refl. R _m _{oil}	Vol. M. d. a. f. %
German	USA		
Torf	Peat	0.2	68
Weich- Matt- Glanz- Flamm- Gasflamm- Gas- Fett- Ess- Mager- Anthrazit Meta-Anthr.	Lignite	0.3	64
		0.3	60
	Sub- Bit.	0.4	56
		0.4	52
	C	0.5	48
		0.6	44
	B	0.7	40
		0.8	36
	A	1.0	32
		1.2	28
Braunkohle Steinkohle	High Vol. Bituminous	1.4	24
		1.6	20
	Medium Volatile	1.8	16
		2.0	12
	Low Volatile	3.0	8
		4.0	4
	Semi-Anthracite		
	Anthracite		
	Meta-A.		

Figure 4.13: Correlation of reflectance (R_m) and volatile matter (V.M.): from Stach (1975).

V.M.~40. Reflectance may vary with composition so a single data point must be regarded with suspicion. However, taken at face value, the measured coal rank of this sample appears to correspond to zeolite facies metamorphism, roughly comparable with the lower stability field of the laumontite-albite-quartz assemblage.

4.5 SYNTHESIS AND DISCUSSION

Evidence from examination of vein minerals, clay mineral transformations and a single coal sample is in rough agreement in suggesting that the Esk Head Mélange attained a consistently low metamorphic grade within the Esk Head/Okuku area. Both "blocks" and matrix appear to have achieved roughly equivalent metamorphic grade. Vein relationships within mélange samples suggest that metamorphism was an ongoing process during mélange formation. It appears that the constituents of the Esk Head Mélange never achieved burial depths greater than 15 km. Moreover, these rocks do not appear to have attained a temperature significantly greater than 200°C. Regionally, rocks of the Torlesse at prehnite-pumpellyite metamorphic grade are found to the southwest of the study area while zeolite to prehnite-pumpellyite grade rocks occur to the northeast (Landis and Bishop, 1972).

The evidence discussed in this chapter suggests shallow burial metamorphism, but is not inconsistent with metamorphism in the upper levels of a subduction zone. Metamorphism in the "external zone" of the (Swiss) Alps, postulated to be subduction-related, passes from laumontite-albite-quartz grade through prehnite-pumpellyite to albite-amphibolite grade (Ernst, 1975). Within the Torlesse/Haast Schist, a similar increase in metamorphic grade southwestward has been postulated to reflect a westward dipping subduction zone (Landis and Bishop, 1972).

Metamorphism in the Esk Head Mélange is not inconsistent with burial at shallow levels in a similar subduction zone.

CHAPTER FIVE

STRUCTURE

5.1 INTRODUCTION

This chapter deals with a) the structure of the Esk Head/Okuku area as a whole and b) the structural fabric of the Esk Head Mélange and processes which are inferred to have created this fabric. It is suggested that the Esk Head Mélange represents a "structural marker" which has been affected by post-mélange tectonic events. Post-mélange flattening has modified the fabric of the zone and later folding and faulting are responsible for the present configuration observed.

The fabric of the mélange zone will first be briefly reviewed and then the structure of the Esk Head/Okuku area will be discussed. This discussion is presented in reverse chronologic order, with the youngest, most obvious structures discussed first.

5.2 FABRIC OF THE MÉLANGE ZONE

On a map scale, the Esk Head Mélange is a structurally coherent body, with a systematic fabric defined by mélange fabric, shear fabric and bedding orientation. In this sense, although mixing has occurred, the zone is not totally chaotic. Planar fabrics within and marginal to the mélange zone are steeply dipping (generally 75°) to the northwest and trend generally NW-SE. No large scale imbrication is noted. Younging directions are difficult to establish because of the degree of disruption of beds. (Way up directions were established principally from truncated ripple laminations but sparse flame structures, scour features, and grading within individual sandstone beds were also used

locally.) Overall, beds within and surrounding the *mélange* zone young to the SW, and are steeply overturned. Local facing changes are noted in a few areas and will be discussed below. The orientation of planar fabrics was measured within little-disrupted bedded units, sheared lithologies and *mélange*. The overall fabric of the *mélange* zone is a composite of *mélange* fabric, shear fabric and bedding attitude.

5.2.1 *Mélange* fabric

Mélange fabric was measured principally within the blocky/laminar *mélange* matrix association (introduced in chapter 3) which is predominant in the *mélange* zone overall. *Mélange* fabric and deformation style was examined in outcrop and in polished slab and thin section.

In outcrop, a planar *mélange* fabric is defined by 1) the alignment of bladed to discoid "blocks", 2) an irregular anastomosing cleavage within the matrix, 3) within "laminar" *mélange* matrix, by an irregular "banding" defined by siltstone "streamers" within dark matrix (see figure 3.30). Smaller pebble-size "blocks" and matrix cleavage commonly sweep around larger metre-plus size "blocks" and the *mélange* fabric is believed to be anastomosing on all scales, from microscopic to map scale. Fabric orientation recorded for a locality is the overall attitude with minor variations ignored. It represents the "outcrop scale" fabric, not the hand specimen or individual plane orientation. In the field, *mélange* fabric is always found to be parallel to adjacent "shear fabric" (see below) suggesting a related origin. Furthermore, bedding attitude within intact sequences is always roughly parallel to adjacent *mélange* fabric. In these cases, bedded elements are thought to be "rafts", floating in *mélange* matrix and aligned subparallel to *mélange* fabric.

5.2.2. Shear fabric

Shearing is evident throughout the Esk Head Mélange and margins. Interbed shearing is most commonly observed, where shear planes are parallel or subparallel to bedding and movement has taken place along muddy interbeds. Propagation of low angle shears through sandstone beds commonly accompanies interbed shearing and produces a shear fabric of elongate "shear lenses" (figure 5.1). A similar penetrative fabric of "anastomosing shear surfaces" has been described from the Franciscan Complex of California (Cowan, 1974; Korsch, in press). Within the Esk Head Mélange, such a "shear fabric" is dominated by interbed shearing and is parallel or subparallel to bedding. A similar "shear fabric" or "sheared pillow fabric" is common to volcanic units. While the anastomosing nature of shear planes makes the attitude of "shear fabric" somewhat variable, overall orientations were recorded for individual outcrops. Shear fabric is recorded in units which contain too little matrix, or are not so highly disrupted to be considered blocky mélange, but where shearing has advanced to the point where bedding cannot be discerned. This "shear fabric" is parallel or subparallel to neighbouring mélange fabric and bedding. In cases with more abundant mudstone, similar shearing results in isolated, very elongate "blocks" of sandstone or siltstone in a sheared muddy matrix (figure 5.2).

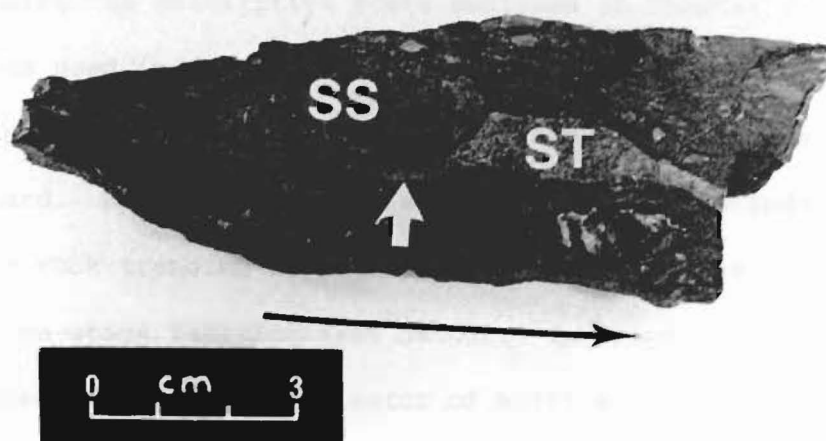
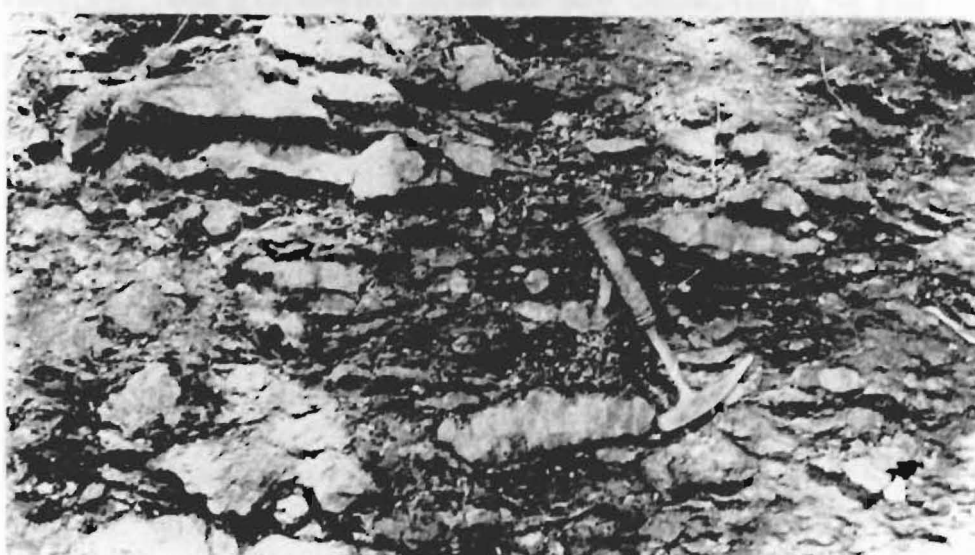
5.2.3 Stereoplots, domains and fabric

The fabric of the mélange zone and margins, folding and faulting is displayed in stereoplots, (figure 5.4 a to k). Data has been plotted in a number of structural "domains" shown in figure 5.3. Domains have been selected as distinct geographic areas and may include area of mélange zone plus associated margins. Where possible, major late stage faults have been used as domain boundaries.

Figure 5.1: "Shear fabric" in sandstone/mudstone unit.

Figure 5.2: Elongate "shear lenses" of sandstone in sheared muddy matrix.

Figure 5.5: Polished slab: siltstone lens (ST) flattened against and extending from neighbouring sandstone "block" (SS). White arrow indicates portion of siltstone unit compressed against sandstone. Black arrow indicates approximate trend of *mélange* fabric.



Planar fabrics within individual domains are dispersed about an average fabric which strikes Northeast/Southwest and dips steeply Northeast. The trace of the average fabric is shown on stereoplots for individual domains. M \acute{e} lange, shear and bedding fabric display no consistent variation or concentration into individual fields.

The dispersion of poles to planar fabrics does not display any convincing concentration along π girdles within individual domains, and the fabric of the m \acute{e} lange zone is not regarded as the product of large scale folding. The dispersion observed may conceivably be the result of several generations of folding along intersecting, steeply plunging axes, but observed minor folding does not support this contention. Rather, field evidence suggests that m \acute{e} lange and shear fabric are anastomosing and define an irregular or lensoid fabric on outcrop and map scale. Measured orientation of individual planar fabrics within this lensoid type of large scale fabric has resulted in the dispersed pattern observed.

5.2.4 "Degree of disruption"

The degree of disruption of sandstone lithologies was noted in the field using the descriptive scale outlined in chapter 2. This technique was used in the hope of delineating zones of disruption related to m \acute{e} lange formation, but does not appear to provide any insight in this regard. Rather the scale, as applied, seems to indicate zones of fractured rock trending subparallel to, or coinciding with northeast-trending, late stage faulting (see below). In practice, the "disruption scale" has become purely an indicator of brittle fracture, where "highly disrupted sandstone" records the presence or proximity of late-stage faulting. In fact, isolated northeast-trending "shear fabric" orientations may represent a brittle fracture pattern imposed locally by

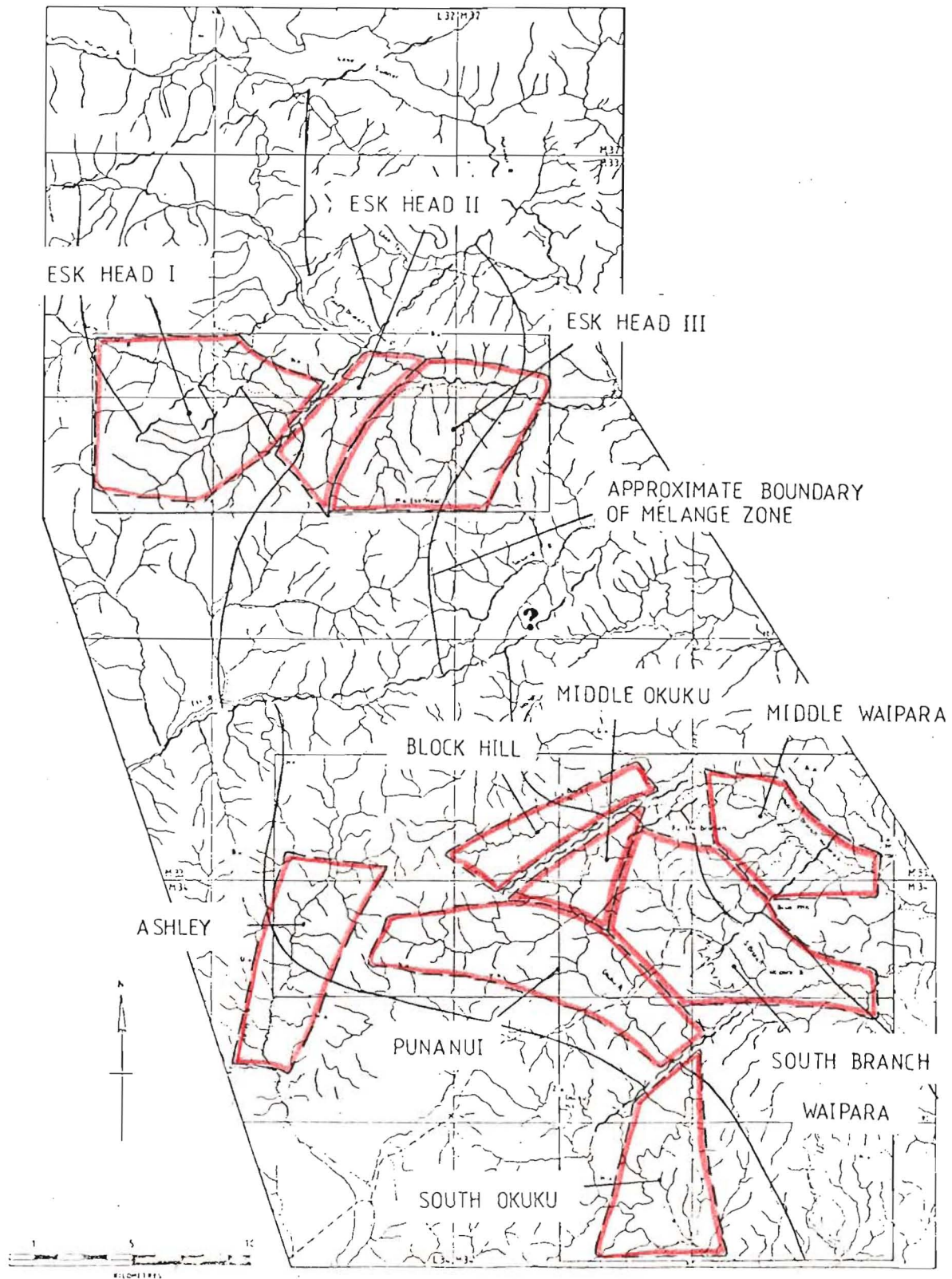
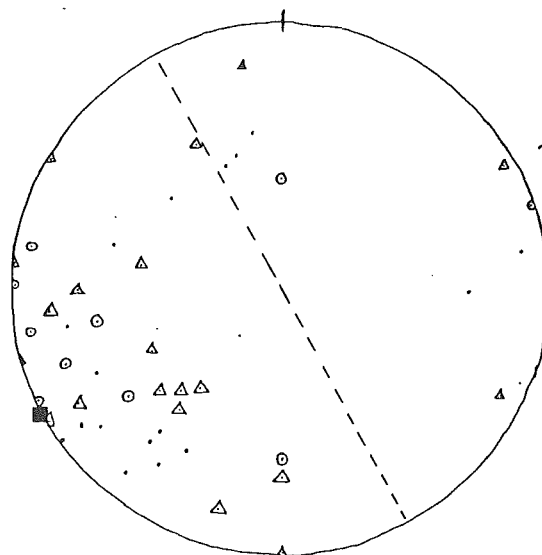


FIGURE 5.3: Location of structural domains

PLANAR FABRIC



POLES TO:

• BEDDING

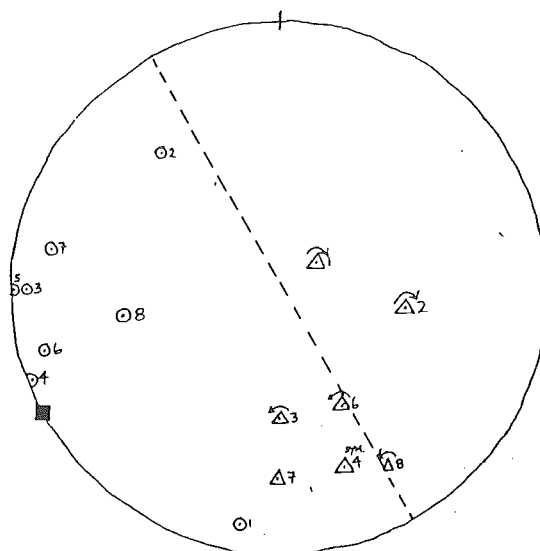
△ SHEAR FABRIC

○ MÉLANGE FABRIC

--- Trace of average fabric

■ Pole to av. fabric

FOLDS

○ POLE TO
AXIAL PLANES

△ HINGE

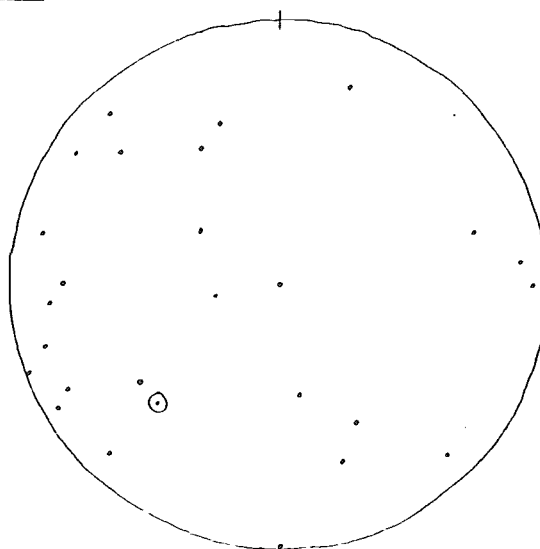
Symmetry:

△ Dextral

△ Sinistral

△ Symmetrical

FAULTS and cleavage



POLES TO:

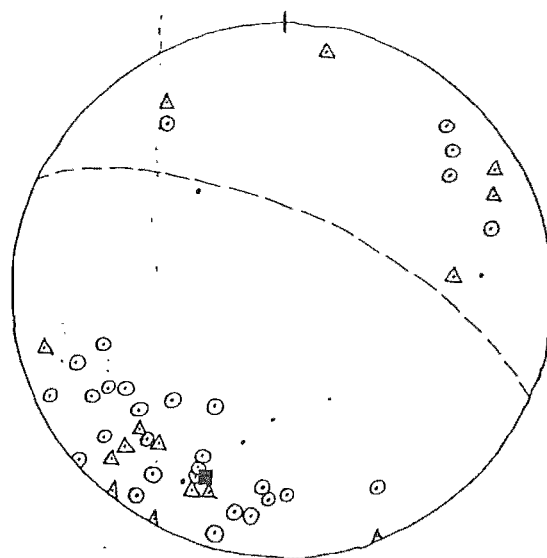
□ LATE FAULTS
(extensive gouge)

△ Fracture cleavage

• Unspecified faults

○ EARLY FAULTS

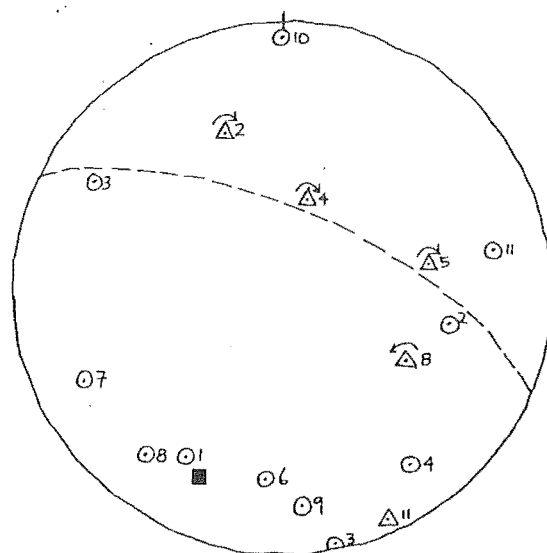
PLANAR FABRIC



POLES TO:

- BEDDING
- △ SHEAR FABRIC
- ⊙ MÉLANGE FABRIC
- Trace of average fabric
- Pole to av. fabric

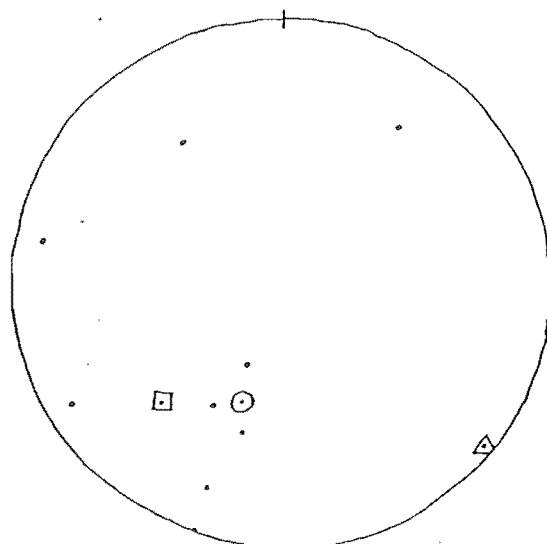
FOLDS



POLE TO
AXIAL PLANES

- △ HINGE
- Symmetry:
- △ Dextral
- △ Sinistral
- △ Symmetrical

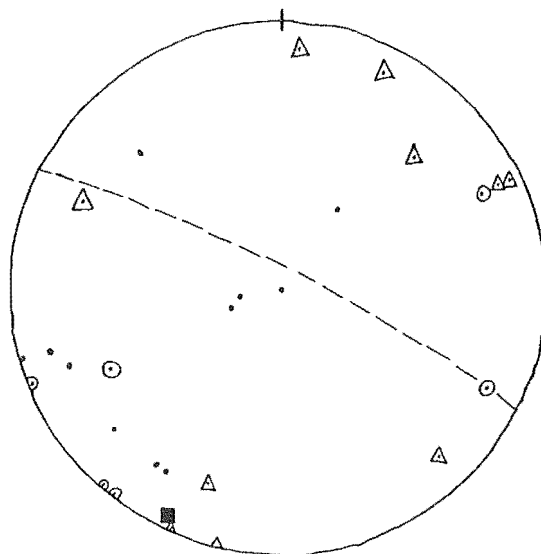
FAULTS and cleavage



POLES TO:

- LATE FAULTS
(extensive gouge)
- △ Fracture cleavage
- Unspecified faults
- ⊙ EARLY FAULTS

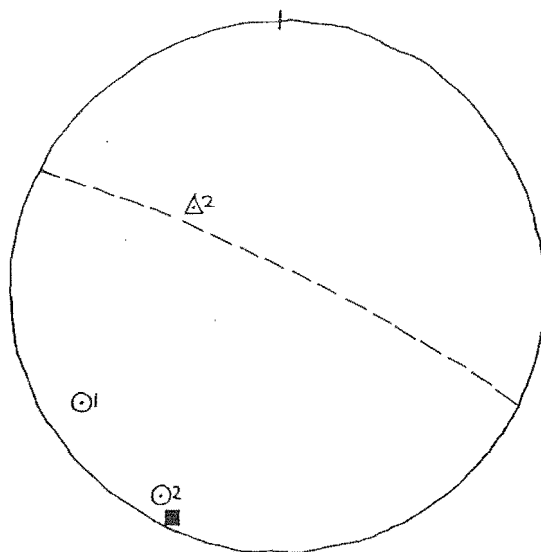
PLANAR FABRIC



POLES TO:

- BEDDING
- △ SHEAR FABRIC
- ⊙ MÉLANGE FABRIC
- Trace of average fabric
- Pole to av. fabric

FOLDS



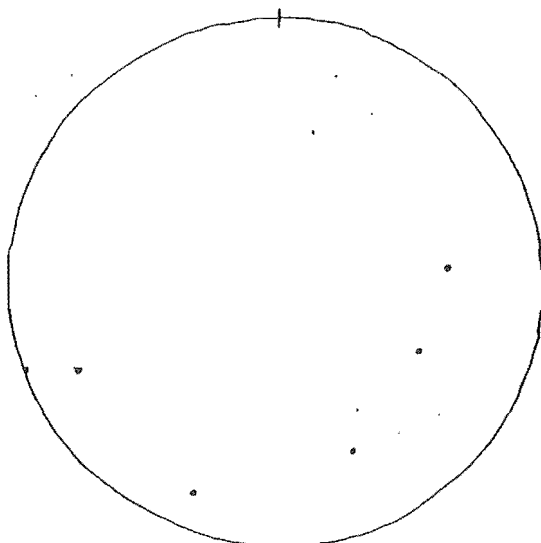
POLE TO AXIAL PLANES

△ HINGE

Symmetry:

- △ Dextral
- △ Sinistral
- △ Symmetrical

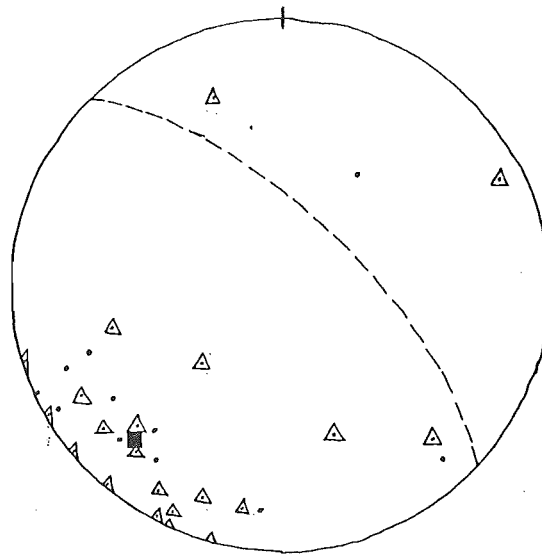
FAULTS and cleavage



POLES TO:

- LATE FAULTS
(extensive gouge)
- △ Fracture cleavage
- Unspecified faults
- ⊙ EARLY FAULTS

PLANAR FABRIC



POLES TO:

• BEDDING

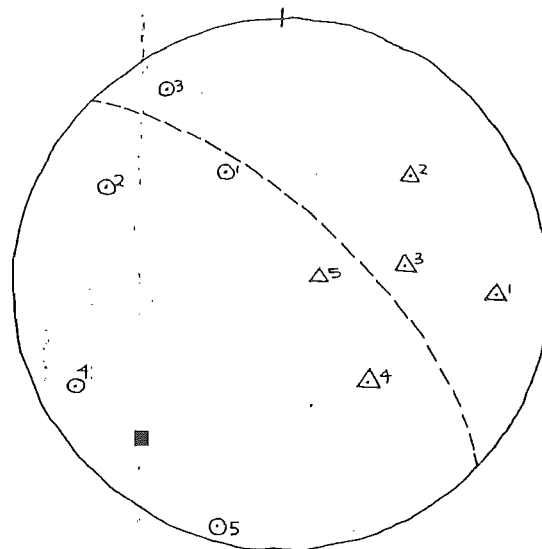
△ SHEAR FABRIC

⊙ MÉLANGE FABRIC

--- Trace of average fabric

■ Pole to av. fabric

FOLDS



POLE TO
⊙ AXIAL PLANES

△ HINGE

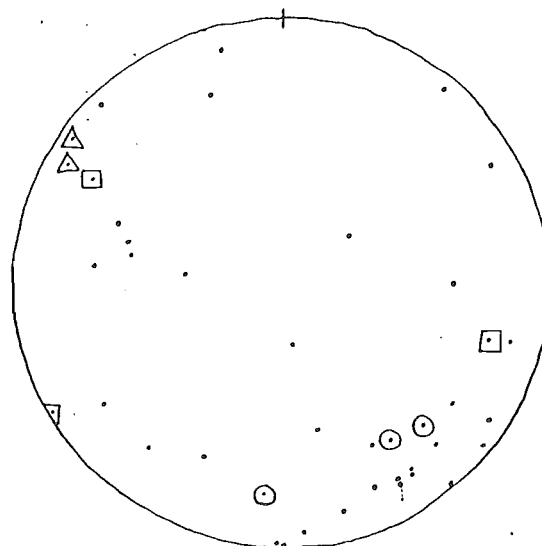
Symmetry:

△ Dextral

△ Sinistral

△ Symmetrical

FAULTS and cleavage



POLES TO:

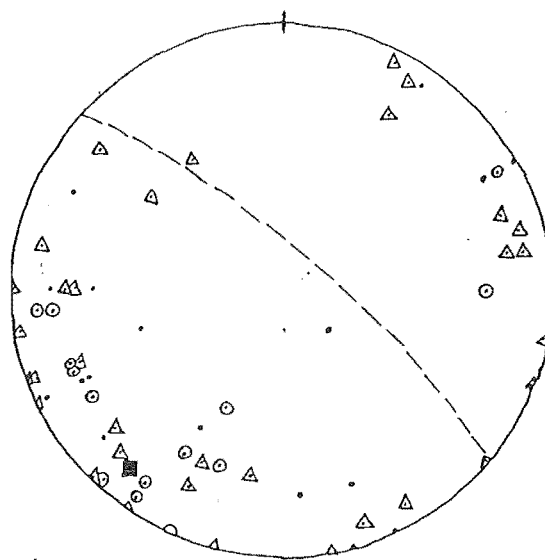
□ LATE FAULTS
(extensive gouge)

△ Fracture cleavage

• Unspecified faults

⊙ EARLY FAULTS

PLANAR FABRIC



POLES TO:

• BEDDING

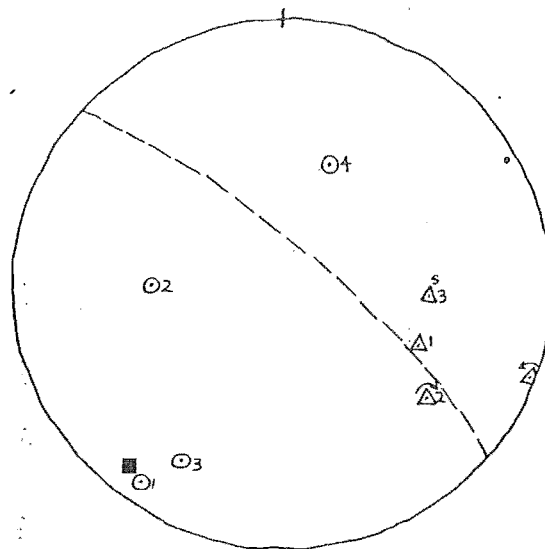
△ SHEAR FABRIC

○ MÉLANGE FABRIC

--- Trace of average fabric

■ Pole to av. fabric

FOLDS

○ POLE TO
AXIAL PLANES

△ HINGE

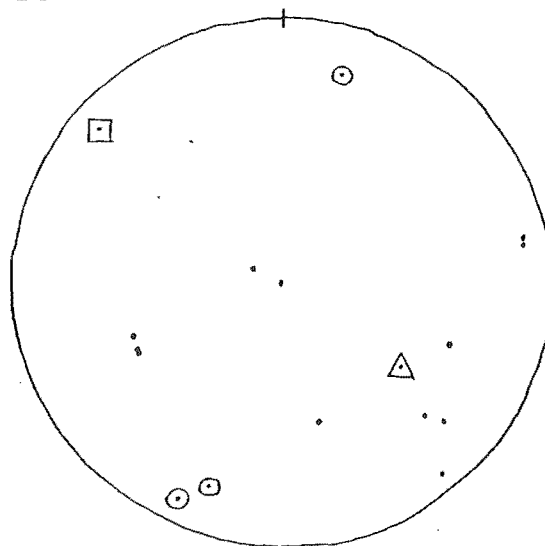
Symmetry:

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△ Sinistral

△ Symmetrical

FAULTS and cleavage



POLES TO:

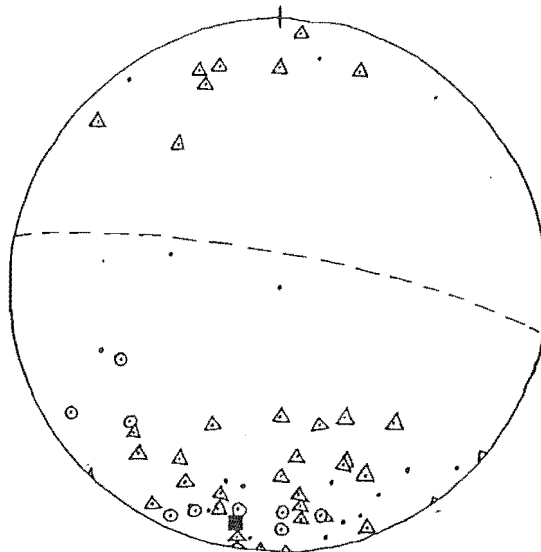
□ LATE FAULTS
(extensive gouge)

△ Fracture cleavage

• Unspecified faults

○ EARLY FAULTS

PLANAR FABRIC



POLES TO:

• BEDDING

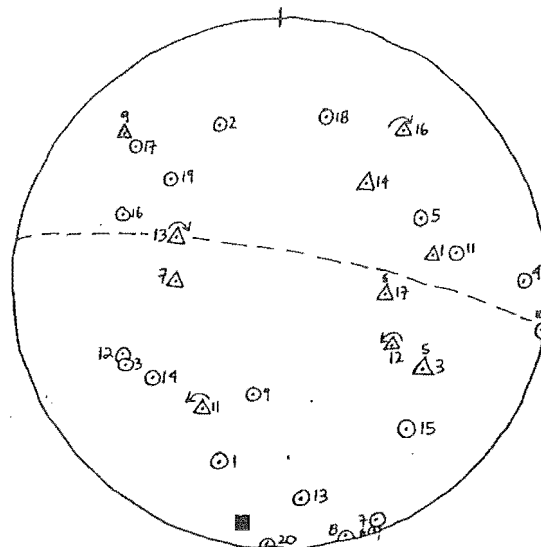
△ SHEAR FABRIC

○ MÉLANGE FABRIC

--- Trace of average fabric

■ Pole to av. fabric

FOLDS



○ POLE TO AXIAL PLANES

△ HINGE

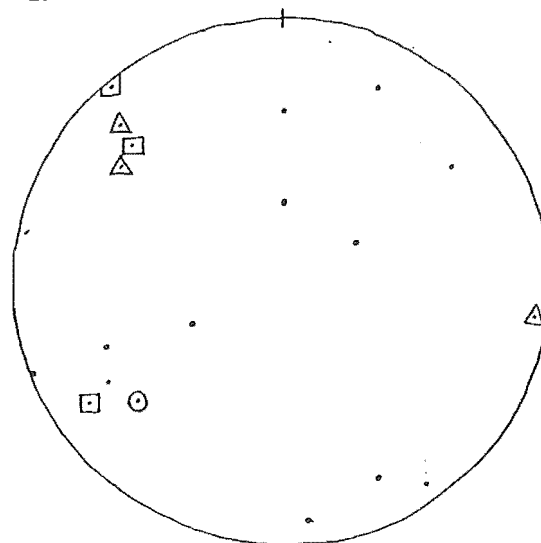
Symmetry:

△ Dextral

△ Sinistral

△ Symmetrical

FAULTS and cleavage



POLES TO:

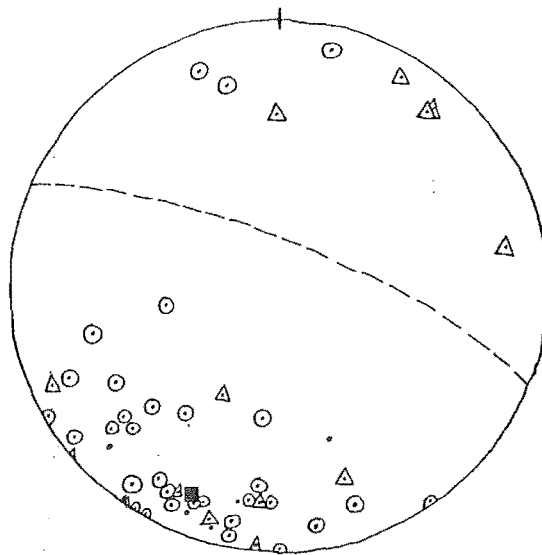
□ LATE FAULTS
(extensive gouge)

△ Fracture cleavage

• Unspecified faults

○ EARLY FAULTS

PLANAR FABRIC



POLES TO:

• BEDDING

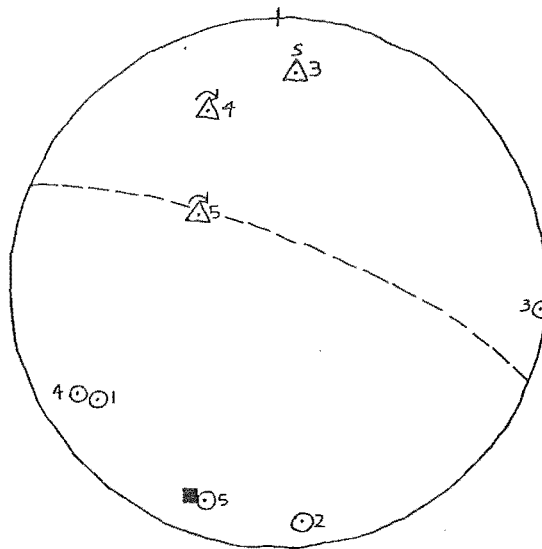
△ SHEAR FABRIC

○ MÉLANGE FABRIC

--- Trace of average fabric

■ Pole to av. fabric

FOLDS

○ POLE TO
AXIAL PLANES

△ HINGE

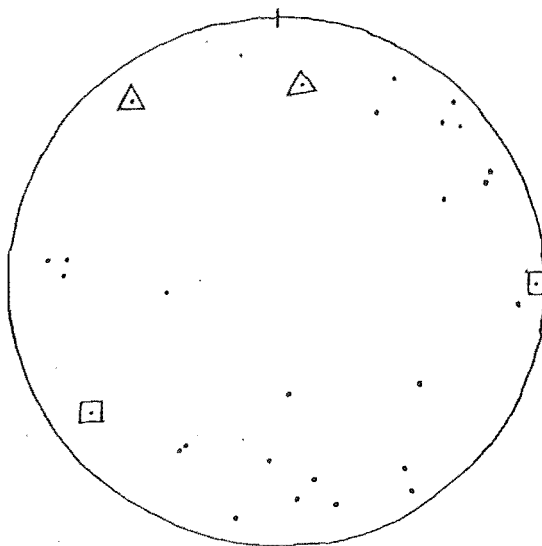
Symmetry:

△ Dextral

△ Sinistral

△ Symmetrical

FAULTS and cleavage



POLES TO:

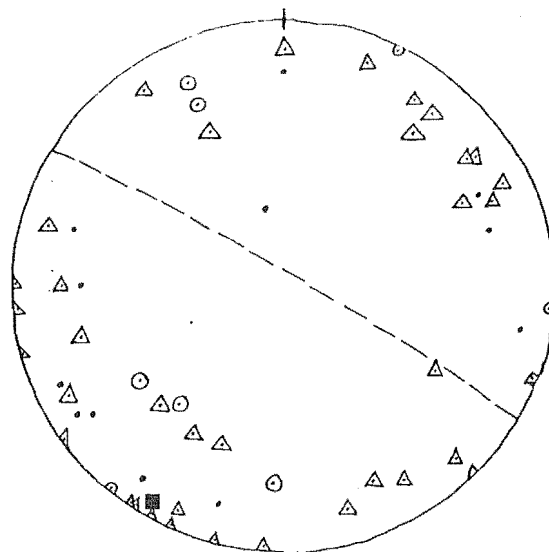
□ LATE FAULTS
(extensive gouge)

△ Fracture cleavage

• Unspecified faults

○ EARLY FAULTS

PLANAR FABRIC



POLES TO:

• BEDDING

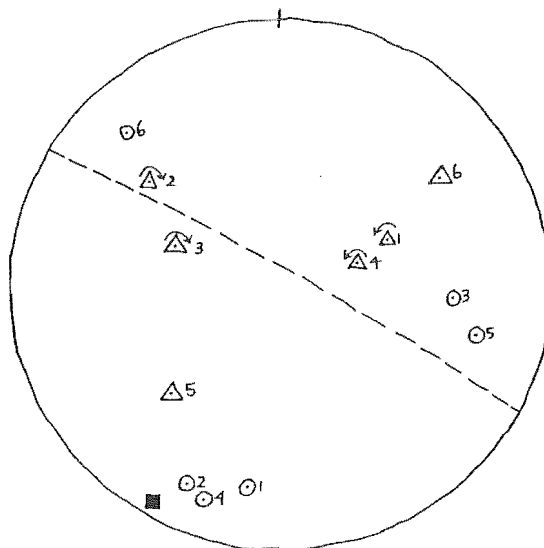
△ SHEAR FABRIC

⊙ MÉLANGE FABRIC

--- Trace of average fabric

■ Pole to av. fabric

FOLDS



POLE TO
⊙ AXIAL PLANES

△ HINGE

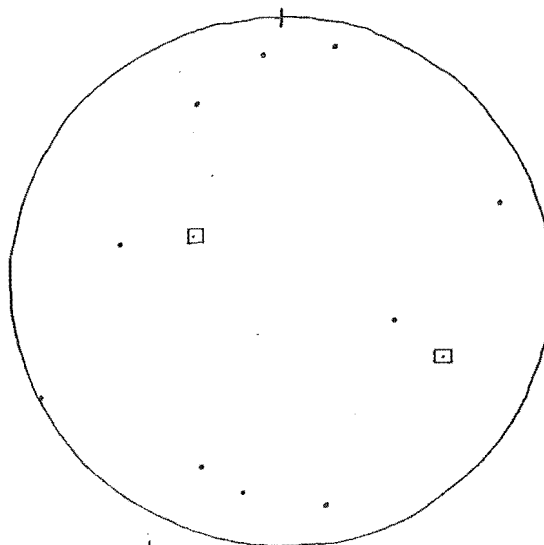
Symmetry:

△ Dextral

△ Sinistral

△ Symmetrical

FAULTS and cleavage



POLES TO:

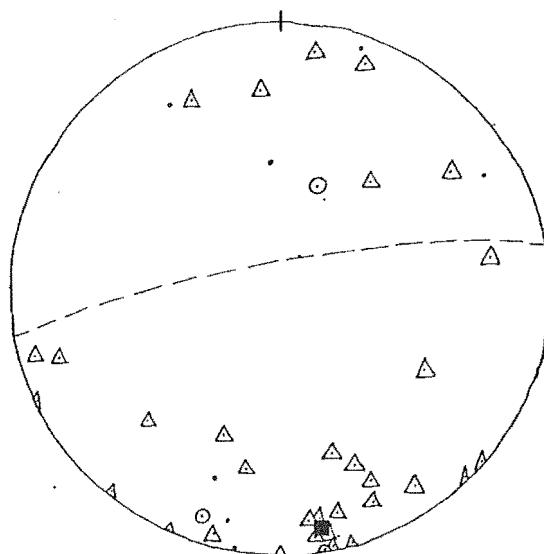
□ LATE FAULTS
(extensive gouge)

△ Fracture cleavage

• Unspecified faults

⊙ EARLY FAULTS

PLANAR FABRIC



POLES TO:

• BEDDING

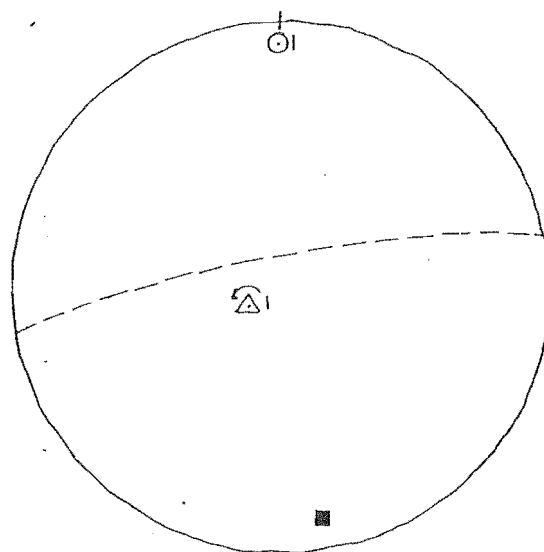
△ SHEAR FABRIC

⊙ MÉLANGE FABRIC

--- Trace of average fabric

■ Pole to av. fabric

FOLDS



POLE TO
⊙ AXIAL PLANES

△ HINGE

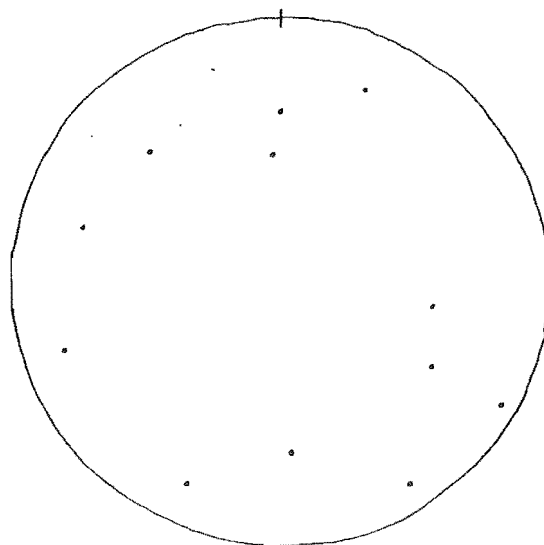
Symmetry:

△ Dextral

△ Sinistral

△ Symmetrical

FAULTS and cleavage



POLES TO:

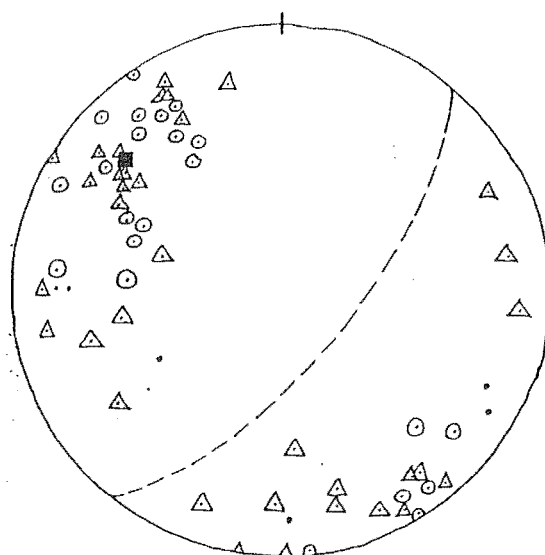
□ LATE FAULTS
(extensive gouge)

△ Fracture cleavage

• Unspecified faults

⊙ EARLY FAULTS

PLANAR FABRIC



POLES TO:

• BEDDING

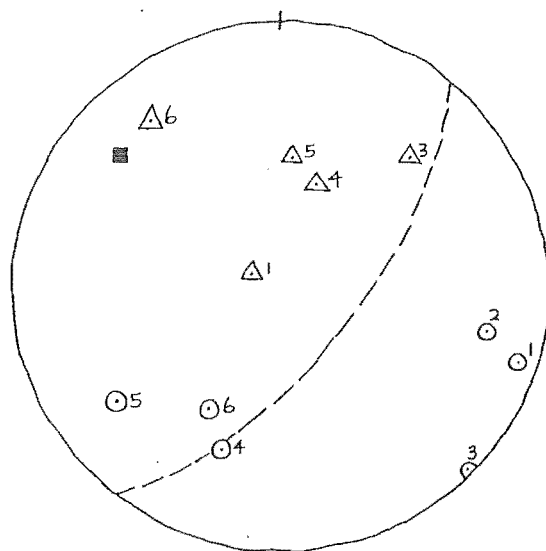
△ SHEAR FABRIC

○ MÉLANGE FABRIC

--- Trace of average fabric

■ Pole to av. fabric

FOLDS



○ POLE TO AXIAL PLANES

△ HINGE

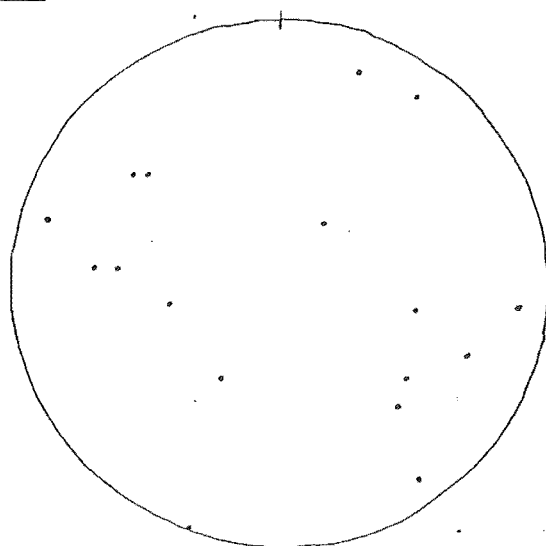
Symmetry:

△ Dextral

△ Sinistral

△ Symmetrical

FAULTS and cleavage



POLES TO:

□ LATE FAULTS
(extensive gouge)

△ Fracture cleavage

• Unspecified faults

○ EARLY FAULTS

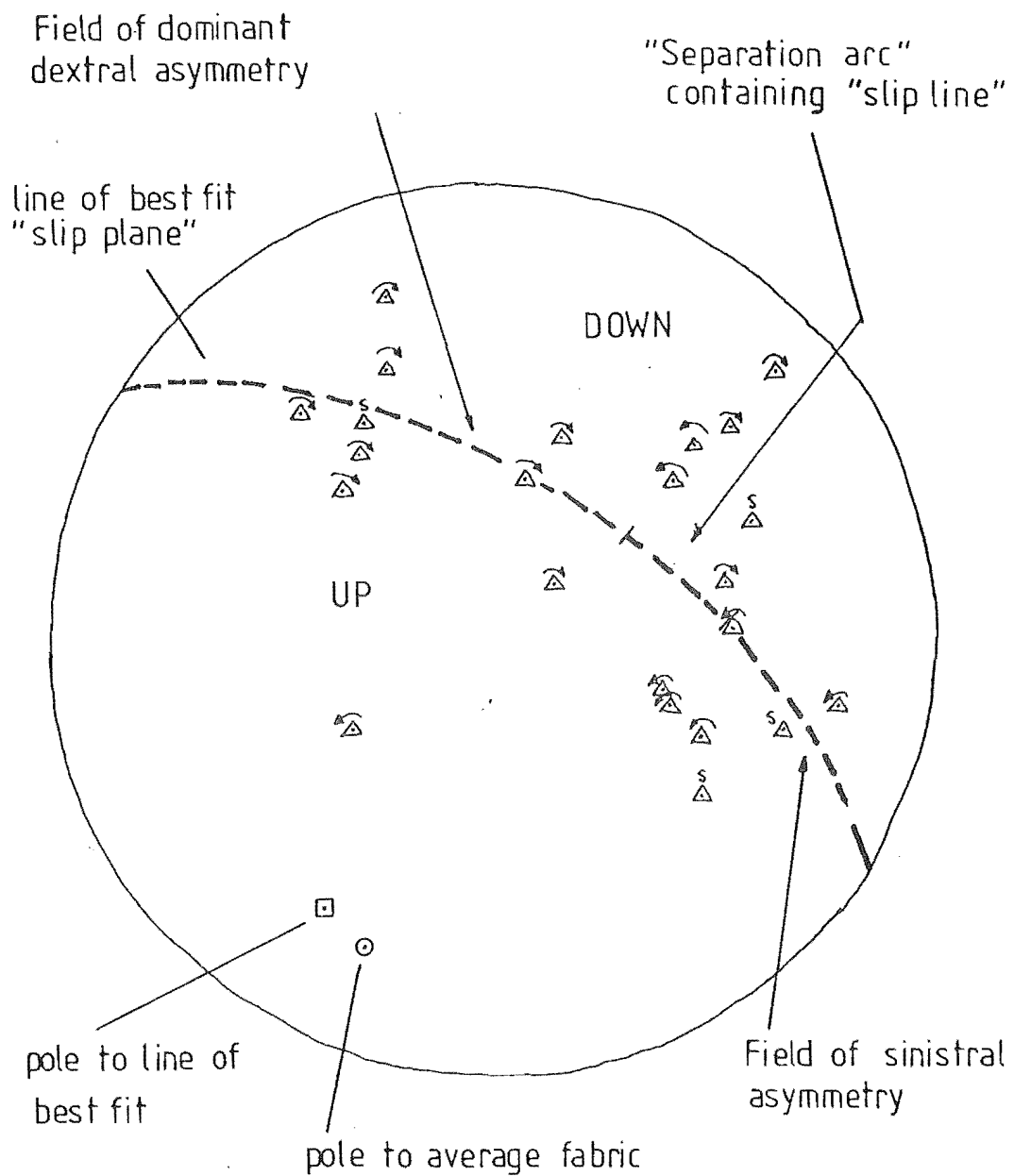


FIGURE 5-4 k) : Composite plot of asymmetric (group 4)
fold hinges, corrected to average
(Punanui) fabric.

northeast trending faulting. (The Middle Waipara domain provides an example in stereoplot and map).

5.3 KAIKOURA DEFORMATION : FAULT REACTIVATION?

Late stage northeast trending faults offset the boundary of the *mélange* zone in a sinistral sense (see geologic summary map). Sinistral horizontal displacements in the order of 1 to 3 km are mapped. Fault zones seen in the field are characterized by broad zones of fault gouge up to 10 m in width which commonly display individual discrete fault planes up to 1 cm wide, highlighted by dark carbonaceous material. A discrete fault plane is observed cutting alluvium in the Okuku River (ca.M33/569 028) and here indicates southeast downthrow. These discrete planes may represent the most recent movement planes within the fault zone. They are commonly closely dispersed about a vertical dip and seem to occur as anastomosing sets along individual fault zones.

The most obvious late stage faults trend northeast/southwest. Fault planes strike generally 030° to 050° . The dip of these planes is variable by everywhere greater than 55° .

Fault zones similar in appearance to those described above, with extensive gouge, occur subparallel to *mélange* fabric (see accompanying fabric plots, e.g. Punanui), where sense of displacement cannot be determined. Discrete fault planes within such zones generally strike approximately 140° and commonly dip steeply to the northeast.

Interpretation: The faults described, characterized as relatively wide zones with extensive gouge, are regarded as the most recent deformation suffered by the Esk Head/Okuku area. The sinistral offset of the *mélange*

zone along these faults is inconsistent, however, with the regime of dextral shear demonstrated to occur in North Canterbury/Marlborough during the Kaikoura orogeny (Walcott, 1978). Recent dextral offset occurs along major faults such as the Clarence, Hope and Motonau faults (Carter and Carter, 1982). The recent study by Carter and Carter suggests that the Esk Head/Okuku area is situated on the Conway microplate, which is bounded by the Motanau and Hope fault systems. Within the microplate, block faulting consistent with dextral transcurrent movement on the bounding master faults is thought to occur. Block faulting has a general NNE trend and may be dominated by vertical movement.

A group of major northeast trending Kaikoura faults is mapped in the Esk Head subterrane to the east by Bradshaw (1972). These faults display recent southeast downthrow, resulting in westward dipping fault blocks. Bradshaw notes evidence of pre-Cenozoic faulting and suggests that these faults were initiated during the later part of the Rangitata Orogeny.

In the Esk Head/Okuku area, it appears that Kaikoura deformation is manifested as movement along pre-existing, northeast trending faults. While recent movement may have a horizontal dextral component, this has not been demonstrated in this study. Net horizontal displacement of the Esk Head Mélange remains sinistral in sense. Kaikoura movement may be confined to block faulting with a largely vertical component. The major northeast trending faults mapped are believed to be related to a pre Kaikoura (Rangitata) phase of sinistral faulting and flexuring discussed below.

5.4 POST MÉLANGE STRUCTURE : MESOZOIC

5.4.1 Gentle Flexures and sinistral faults

The mapped boundaries of the mélangé zone are folded into several broad, gentle to open flexures, with northeast/southwest trending axial plane traces and apparently steeply plunging hinges (see geologic summary map). These appear to be related to the same late-stage stress regime which produced the (sinistral) faulted offsets in the mélangé zone, although they do not demonstrate a marked asymmetry. The rotation of regional fabric about near vertical dipping hinges can be noted in comparing the fabric trend of individual domains in stereoplot. The combination of sinistral faulting and flexuring results in a roughly 90° variation of fabric attitude in the Esk Head study area. In the Okuku study area, a 50° variation in fabric strike is noted between the Ashley and Block Hill domains. These appear to be on opposite limbs of the same broad flexure. A group of similar, near vertical plunging gentle flexures is mapped in the Esk Head subterrane to the east (Bradshaw, 1972). The gentle flexures and northeast trending sinistral faults of the Esk Head/Okuku area are regarded as late Rangitata deformations of an already steeply dipping mélangé zone and margins.

A northeast trending, steeply dipping fracture cleavage is evident within some domains. This cleavage commonly occurs as a set of penetrative fractures, occurring at a 5 to 15 cm interval within thick to medium bedded sandstone units. This cleavage is locally and regionally parallel to northeast/southwest trending late stage faulting (see accompanying fabric plots e.g. Middle Branch Waipara) and is thought to be related to the same stress regime which produced the faulting. Fractures are locally calcite filled.

5.4.2 Late stage flattening

Several features suggest that the Esk Head M \acute{e} lange has suffered a late stage flattening, along axes of compression subperpendicular to initial fabric. Sandstone "blocks" within m \acute{e} lange matrix commonly display "goatees" of sandstone or siltstone parallel to or locally defining the m \acute{e} lange matrix. Goatees are commonly composed of siltstone which appears to be plucked or "stripped" from associated "blocks". Figure 5.5 illustrates flattened m \acute{e} lange matrix, where an elongate siltstone has been flattened against a neighbouring sandstone "block" and now appears as a goatee extending from the "block". "Strain-shadows" occupied by new mineral growth do not appear to be present in the m \acute{e} lange zone in outcrop.

A flattened fabric is also noted in thin section, where grains locally display "strain shadows" or "goatees" (see chapter 4 - Metamorphism). Veins oriented at a high angle to m \acute{e} lange fabric are commonly buckled (see figure 4.9). Shelley (1968), suggests that similar bending of veins results not from buckling but from the expansion of vein material during growth. In this study however, only veins oriented at roughly right angles to m \acute{e} lange fabric are bent and, taking other evidence into consideration, these veins are regarded as buckled during flattening. Individual sandstone grains in m \acute{e} lange commonly display a concentration of platy opaques, within adjacent matrix, on the two opposing faces perpendicular to the flattening axis.

A flattened fabric is never seen at an angle to an original m \acute{e} lange fabric. If flattening occurred roughly perpendicular to an original m \acute{e} lange fabric, the effect would be to enhance the alignment of linear and platy elements in the m \acute{e} lange. Flattening would also result in the flow of a ductile matrix around "blocks" in m \acute{e} lange and contribute

to the plucking of material from blocks and an associated rounding such as shown in figure 3.29.

5.4.3 Megascopic fold : Round Hill area

A tight to isoclinal megascopic fold is inferred on the south Okuku River (M34/584 866) in the vicinity of Round Hill. This is approximately 5 km across strike from the western margin of the *mélange* zone. Folding is suggested by a local facing reversal (within exposure of calcareous conglomerate - see chapter 2) and the occurrence of a minor fold hinge. A synformal fold hinge, plunging 45° SE, with a geometry suggestive of box folding, occurs within a moderately disrupted, medium bedded sandstone sequence. Fold limbs could not be traced because of the nature of the exposure. No facing directions could be determined for the fold hinge itself, but the combination of regional facing direction (SW younging) and the local facing reversal suggest that this is an overturned anticline with an amplitude of at least 600 m.

The significance of this fold is unclear, but since it folds "shear fabric" it is regarded as a post-shearing structure. Steeply plunging synclinal megascopic folds are described from the Esk Head subterrane to the northeast (Bradshaw, 1972). Here these folds appear to be related to tectonic slides mapped in the area and may have formed as recumbent structures and been subsequently rotated into their present near vertical attitude. A similar origin might be postulated for the Round Hill fold although evidence is scanty.

5.4.4 "Shear fractures" and "early faults"

Discrete "shear fractures" are considered an important agent in the fragmentation process during *mélange* formation. They will be discussed in this context in section 5.5 below. Shear fracturing appears

to have been an ongoing process, since "shear fractures" or "shear fracture sets" cut *mélange* matrix at many localities and thus record post *mélange* deformation (figure 5.6). Here "shear fractures" have the effect of 1) dislocating and further mixing lithologies and 2) cutting and dislocating individual "blocks". This increases the overall number of "blocks" and alters block shape (figure 5.7). In several localities "shear fractures" displace extension-fractured boundaries of boudinaged "blocks" (figure 5.8) and boudinage is regarded as preceding shearing overall. The effect of the dislocation and mixing of lithologies accomplished by "shear fractures" is illustrated schematically in figure 5.8. The importance of similar features as mixing agents in the Franciscan Complex of California has been stressed by Korsch (in press).

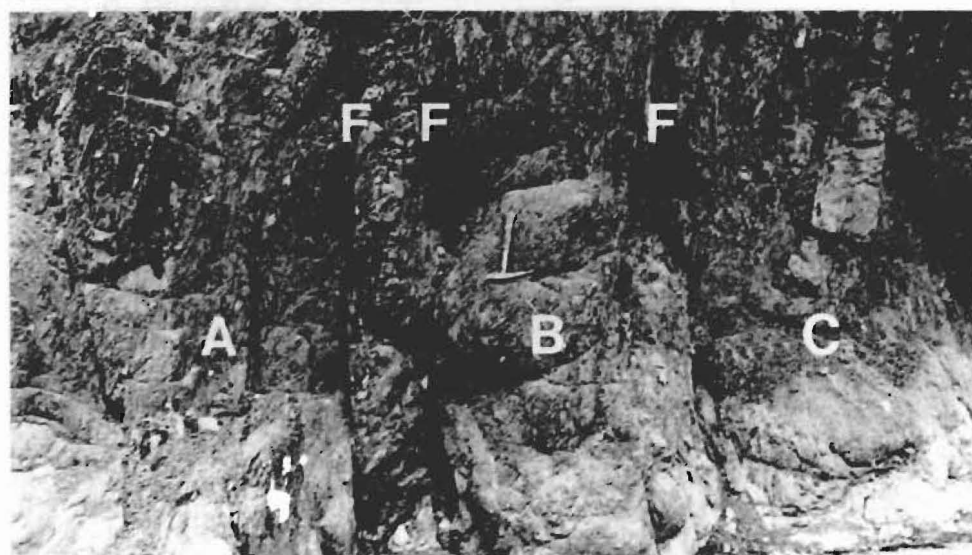
In a similar manner, a group of larger scale features, termed "early faults", displaces and in a sense "readjusts" elements of the *mélange* zone. These faults occur within the *mélange* zone, subparallel to the local fabric and generally steeply dipping. Fault zones are characteristically discrete, less than 5 cm in width, displacing little associated fault gouge or other evidence of brittle deformation. These zones are however, locally highlighted by green, chloritic material along the fault plane. This effect is noted particularly in the vicinity of meta-volcanic units and may represent either 1) the local mobilization and injection of very ductile chlorite along the fault zone or 2) the offscraping of chlorite along the fault trace as a highly altered, chlorite-rich metavolcanic was displaced.

These faults juxtapose various elements of the *mélange* zone, for example: metavolcanics and relatively undisrupted sandstones; metavolcanic-bearing and metavolcanic-free *mélange* matrix, or simply different "styles" of *mélange* matrix (figure 5.9). In this sense, faulting complicates

Figure 5.6: "Shear fractures" crosscutting *mélange* matrix. Hammer is aligned parallel to *mélange* fabric.

Figure 5.7: "Shear fractures" within *mélange* matrix. Long arrow is parallel to *mélange* fabric. Note orthogonal boudinaged margin of sandstone "block" (open curving arrow).

Figure 5.9: Minor "early faults" (F) juxtaposing different "styles" of *mélange* matrix: A) metavolcanic-bearing *mélange* matrix, B) metavolcanic-free blocky *mélange* matrix, C) *mélange* matrix with elongate "blocks" and vague suggestion of stratal continuity.



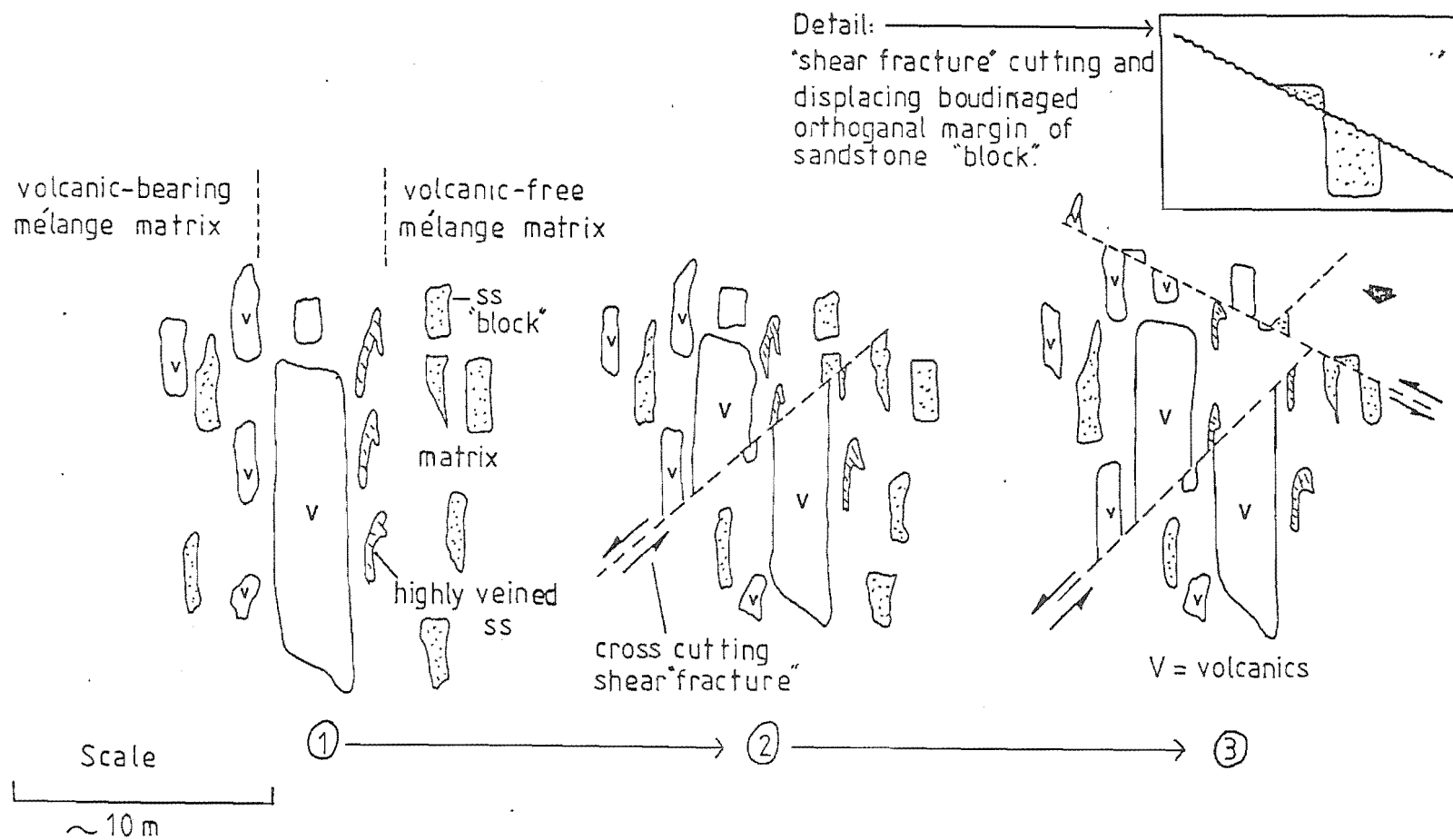


Figure 5.8 Sketch: Progressive disruption and mixing of an idealized mélangé matrix unit by crosscutting "shear fractures".

any attempt to interpret transitional changes in *mélange* matrix style. A larger scale example of early faulting is illustrated in figure 5.10. In this case, metavolcanic rafts are isolated by faulting, subparallel to the fabric, which is itself cut by a late stage fault lying in the plane of the photograph. This example provides the only suggestion of sense of movement on these "early faults". If the two large metavolcanic "blocks" shown were once connected, a northeast downthrow in the order of several hundred metres is implied.

The "early" generation of faulting described cuts and displaces *mélange* and appears to generally postdate the *mélange* flattening event. These faults represent a readjustment of the *mélange* zone and may be 1) faults related to the final stages of *mélange* flattening or 2) strike-slip displacements within the zone.

5.5 SYN MÉLANGE STRUCTURES

Syn *mélange* structures record those processes which fragment and mix lithologies to create *mélange*. Structural features in this section are divided between 1) aspects of the fabric related to fragmentation and 2) fold structures and their role in *mélange* formation.

5.5.1 Origin of "blocks" in a matrix

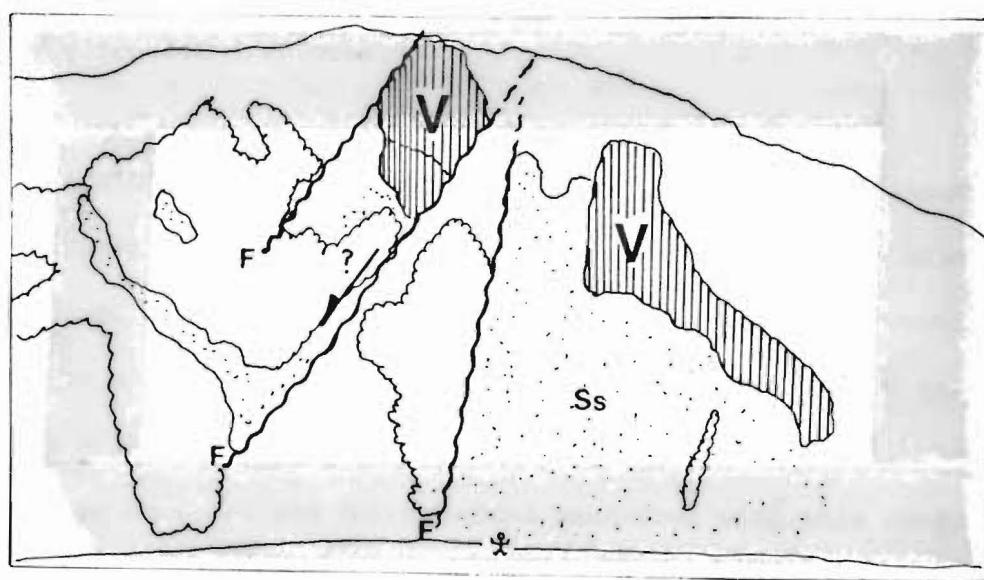
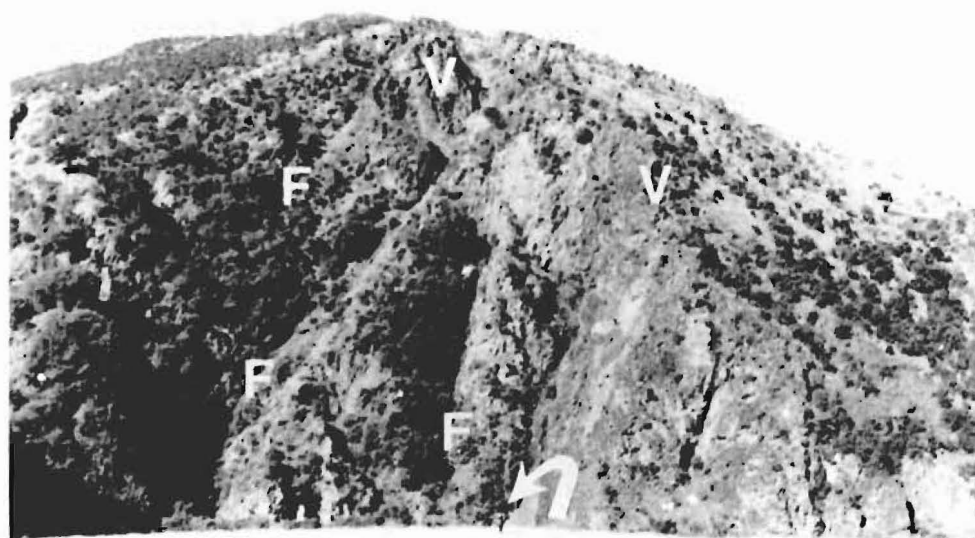
In chapter 3 it was suggested that the blocky/laminar *mélange* matrix is transitional with bedded sandstone/mudstone intervals and appears to have been produced by tectonic processes of boudinage and the disruptive shearing of beds.

Boudinage:

Boudinage is commonly observed in sandstones in the Okuku study area, but more rarely in the Esk Head study area, where shear fabric

Figure 5.10: Major "early faults" (F) subparallel to mélangé fabric, displaying volcanic rafts (V). (View facing southeast; exposure created by late faulting in plane of photograph; figure in foreground (arrow) indicates scale.)

Overlay: Implied sense of fault movement if volcanic rafts were once connected.



predominates. Style of boudinage varies from a gentle pinch and swell to more commonly observed boudins with discrete orthogonal margins, suggesting failure along well defined extension fractures or cross joints. This variation in style depends largely upon the difference in competence between the boudinaged unit and its enclosing material (Ramsay, 1967, p.104). A high competence contrast results in sharp boudin margins, while a low competence contrast results in considerable "necking" and thinning prior to boudin rupture. The pinch and swell structures observed may have formed if strain occurred at an early stage of lithification, when the competence of a water-rich sandstone was close to that of the surrounding mudstone.

Boudinage is observed within 1) relatively intact beds, 2) in broken formation where bedded units are detached by boudinage but still retain a strong suggestion of stratal continuity, and 3) is implied within many units of *mélange* where "block" margins can still be recognized as orthogonal extension fractures.

A transitional boundary between bedded elements and *mélange* matrix is noted in several areas of thick bedded sandstone with thin sandstone interbeds (e.g. on the Upper Okuku River ca.M33/537 031). Several stages of disruption by boudinage are noted in traversing from bedded sandstone/mudstone to *mélange* matrix (figure 5.11). At stage 1 virtually no disruption has occurred and thick bedded sandstone with thin sandstone/mudstone interbeds predominates. At stage 2, thin sandstone interbeds display boudinage while thick sandstone beds remain intact. At stage 3, interbed zones are dominated by dislocated blocks in a muddy matrix while thick sandstone beds retain a strong stratal continuity. These display progressive disruption by boudinage until at stage 4, the lithology consists of isolated "blocks" surrounded by dark muddy matrix. The

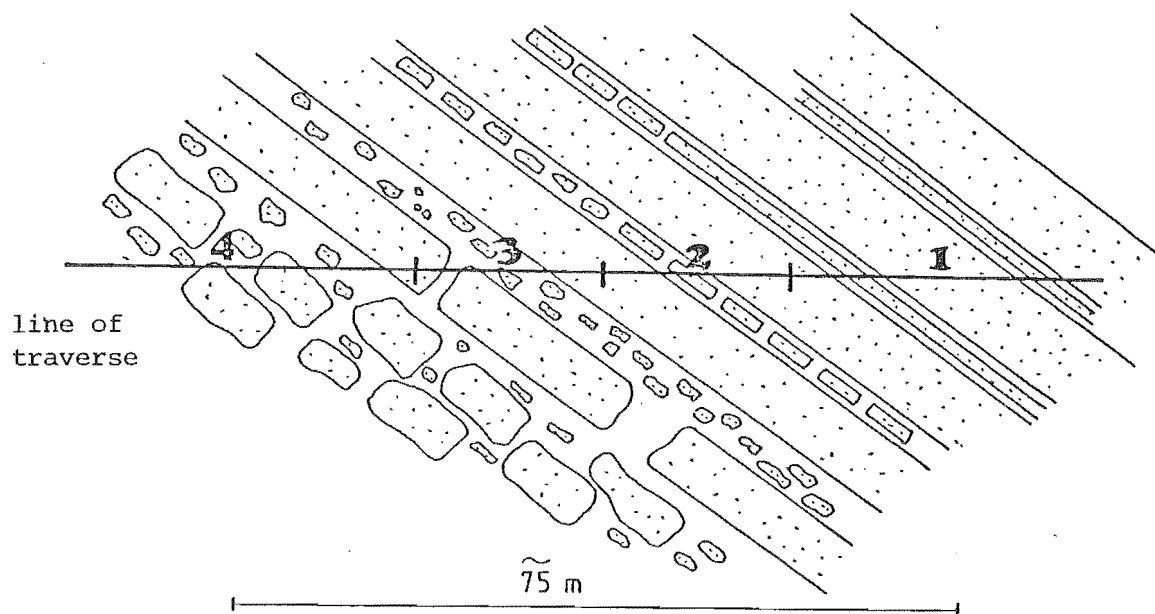


Figure 5.11 Sketch: Transitional boundary between undisrupted thick bedded sandstone/(mudstone) and blocky mélangé matrix. (Based on paced traverse in the upper Okuku River at M33/537 031.)

- Stage 1: Undisrupted thick bedded sandstones with thin sandstone/mudstone interbeds.
- Stage 2: Boudinage of thin sandstone interbeds; thick beds remain intact.
- Stage 3: Interbed zones have become essentially blocky mélangé matrix; thick beds display progressive boudinage.
- Stage 4: Blocky mélangé matrix.

accompanying increase in dark matrix may be an original depositional effect, but matrix appears to be injected into interbed zones in part.

It appears that the boudinage rupturing of a sandstone layer may contribute to the production of isolated "blocks" in matrix in two main ways. If extension occurs in all directions within the layer, "chocolate tablet" boudinage will occur (Ramsay, 1967, p.113). Ramsay suggests that boudinage "axes" will have no uniform linear orientation, but that most could be expected to be subperpendicular to the principal extension. If extension occurs in one principal direction, boudinage will occur at right angles to this direction. Subsequent shearing or faulting at an angle to the boudinaged layer then completes the process of producing isolated blocks. Examples of rotated extension fractured blocks are noted locally (figure 5.12). These are believed to have formed where the principal axis of compression is oriented at an angle to bedding. In such a case, boudinage or extension fracture occurs perpendicular to bedding and boudins are subsequently rotated (Ramsay, 1967, p.109).

The role of shearing in fragmentation:

Shearing is widespread throughout the Esk Head Mélange and margins and is considered to be an important agent in producing the fabric of the zone. The production of a penetrative "shear fabric" by interbed and related low angle shears has been discussed in section 2 above. A related, but somewhat different fabric is created by the combination of interbed shearing and accompanying conjugate shears. If discrete minor conjugate shears (commonly at an angle of approximately 45 degrees to interbed shearing) are exploited during shearing, a fabric of individual sandstone lozenges is created (figure 5.13). This effect is described from mélange and associated deformed rocks in Southern Hawkes Bay, North Island by Pettinga (1982). The distinctive, rhombic "shear lozenge"

Figure 5.12: Rotated extension-fractured block in medium/
thick bedded sandstone/mudstone sequence.

Figure 5.13: Rhombic "shear lozenge" fabric produced by
interbed shears (thin arrow) and conjugate
shears (thick arrow).



fabric created by this combination of interbed shearing and minor conjugate shears appears to be a relatively minor component of the Esk Head Mélange as a whole, however. This process is not considered to be the dominant source of "blocks" in matrix within the Esk Head Mélange.

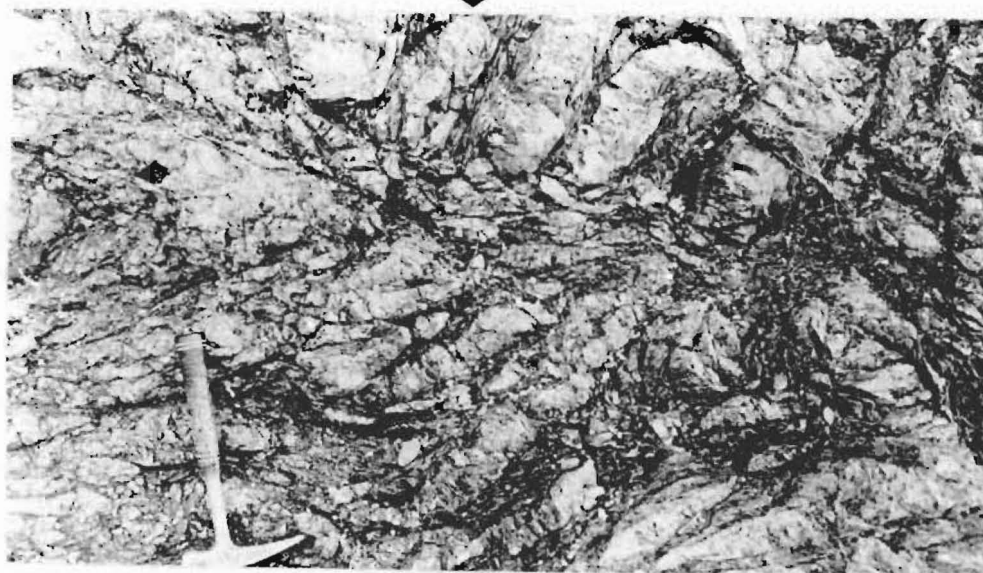
Isolated "shear fractures" appear to be a more important agent in the creation of isolated blocks within matrix. These features are discrete shear planes which generally cut "shear fabric" at a high angle and which commonly demonstrate displacement in the order of 5 cm to several metres. They appear to generally postdate interbed shearing or boudinage effects and are not regarded as simple conjugate shears to interbed shear planes. The effect of shear features in disrupting stratal continuity is illustrated in figure 5.14. Here, over a 10 m interval, a section of thin-bedded sandstone/mudstone displaying minor interbed shearing is disrupted and dislocated to produce isolated blocks in a sheared muddy matrix by the action of "shear fractures". In summary, shear fractures are considered to be 1) important syn mélange structures in disrupting stratal continuity of bedded units to create isolated "blocks" in matrix and 2) important post mélange structures in dislocating and mixing lithologies after initial fragmentation, as discussed in section 4.

Shear "polishing":

Notably in the western regions of the Esk Head/Okuku area the surfaces of sandstone "shear lenses" commonly display shear "lacquering". This is a dark, scaly polish extensively developed along all minor shear planes. In contrast, at a locality within the eastern regions of the mélange zone (South Branch Waipara River M34/619 966) delicate "tool markings" occur on surfaces of an isolated "block" partially weathered out of the surrounding dark matrix. These "brush-like" features occur

**A**

↑
5 M
↓

**B**

↑
5 M
↓

**C**

along the long axes of the "block", subparallel to local fabric, and appear to be impressions formed in a poorly lithified siltstone (figure 5.15).

5.5.2 Evidence from mélangé microfabric

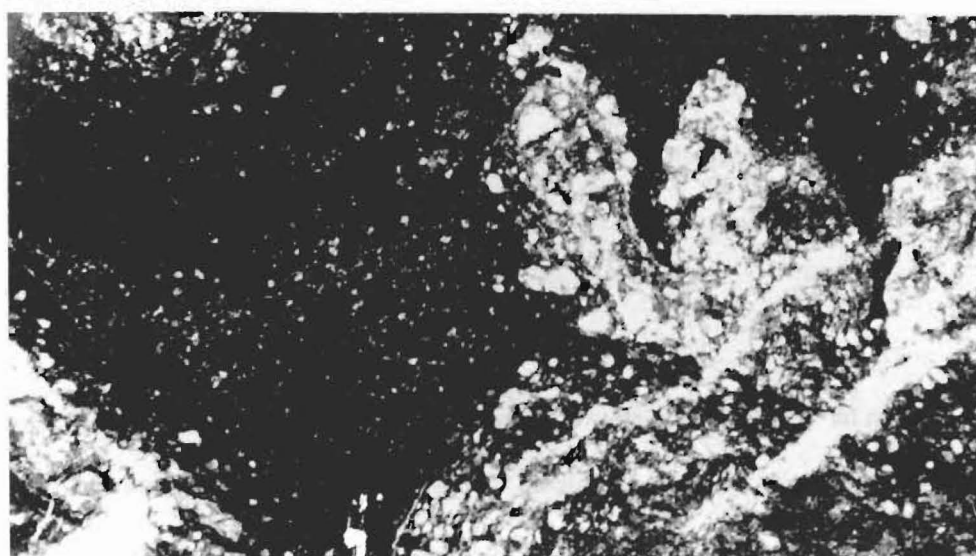
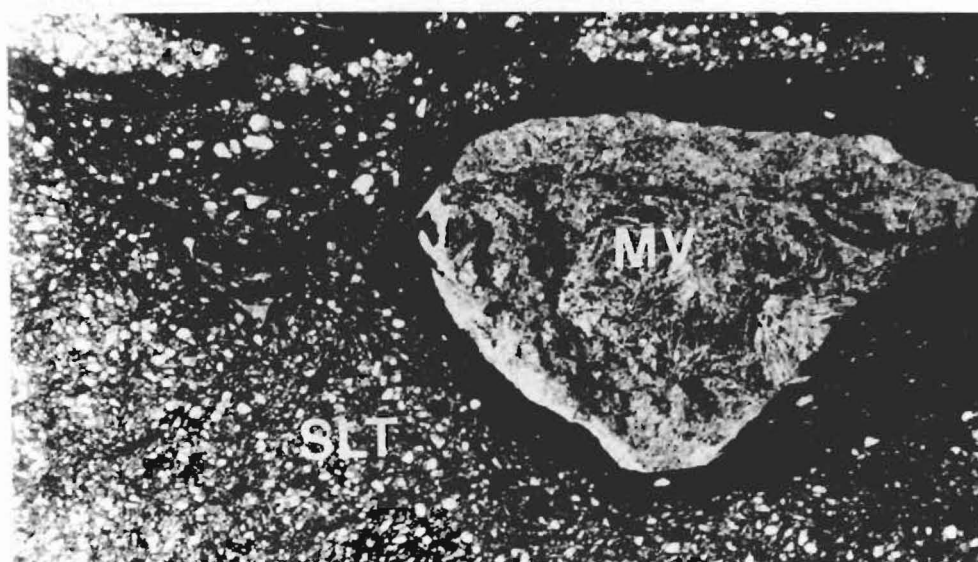
Evidence about the nature of syn mélangé deformation is provided by a study of mélangé microfabric. A total of 34 mélangé matrix samples were examined in thin section and/or polished slab. Characteristics of mélangé formation are suggested by features common to many blocky/laminar mélangé matrix samples. Mélangé samples consist of "blocks" and grains floating in a muddy matrix. "Blocks" are predominantly sandstone but include volcanics, limestone and chert. Sandstones include some medium sandstone, but are dominantly fine sandstone to siltstone. The composition of individual sandstone "blocks" appears to be the same as the overall sandstone composition discussed in chapter 2. On a thin section and hand specimen scale "blocks" and "grains" vary in size from individual medium to fine sandstone grains of quartz, feldspar and volcanic rock fragments, to rock fragments of all lithologies ranging in size upward through coarse and very coarse sandstone, granules, and pebbles (Wentworth size grades). The matrix is dark, semi-opaque in part, and displays an irregular internal fabric defined by the alignment of platy opaques. The matrix appears chloritic in thin section. The clay mineral composition has been described in chapter 4.

Deformation of "blocks" and grains has proceeded in a largely ductile manner. Matrix/block (grain) relationships appear to record the progressive disintegration of generally poorly lithified sandstone/siltstone elements. Figure 5.16 illustrates the soft nature of a siltstone block, where a rounded metavolcanic grain is pressed into its margin. Dark matrix is commonly "injected" along fractures or embayments in

Figure 5.15: Delicate "tool-mark" like features (arrow) preserved on surface of siltstone "block".

Figure 5.16: Metavolcanic grain (MV) pressed into margin of neighbouring siltstone "block" (SLT).
(Field of view approximately 3.4 mm.)

Figure 5.17: Injection of dark matrix along "swirling", embayed margin of sandstone "block".
(Field of view approximately 3.4 mm)



"blocks" and the matrix appears to have behaved as a pressurized fluid-rich medium (figure 5.17). Cataclastic deformation or brittle fractures crosscutting individual grains, is never observed. Rather, individual grains are donated to the matrix whole in the course of sandstone disintegration. Figure 5.17 and 5.18 illustrate this process along typical "swirling", embayed block margins. In some cases, sandstone rock fragments have been plucked from "block" margins through the exploitation of pre-existing fractures (figure 5.19).

A "two-stage" matrix commonly appears as a result of the disintegration process. A slightly opaque, silty matrix, light brown in plane light, commonly surrounds "blocks" and grains or appears as wispy lenses or "goatees" in thin section. A dark, semi-opaque to opaque matrix appears as irregular zones suggestive of movement or solution planes and appears to be a concentration of dark insolubles.

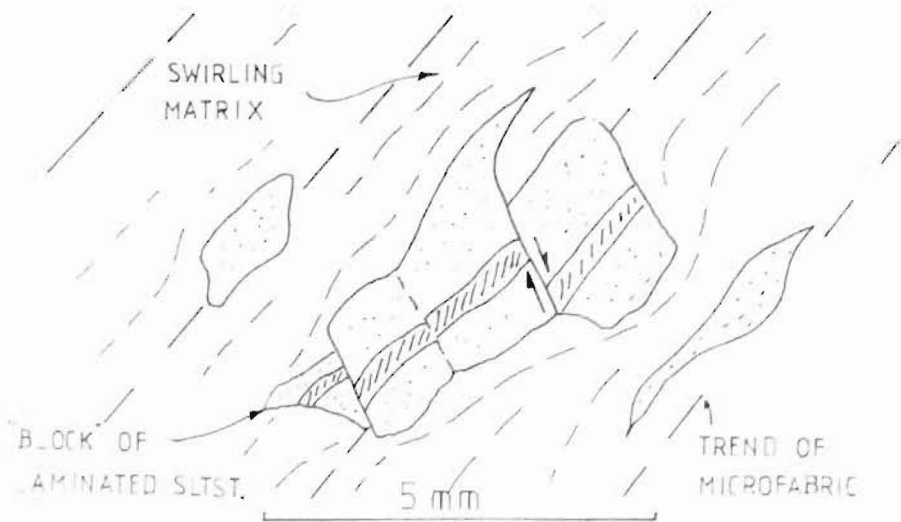
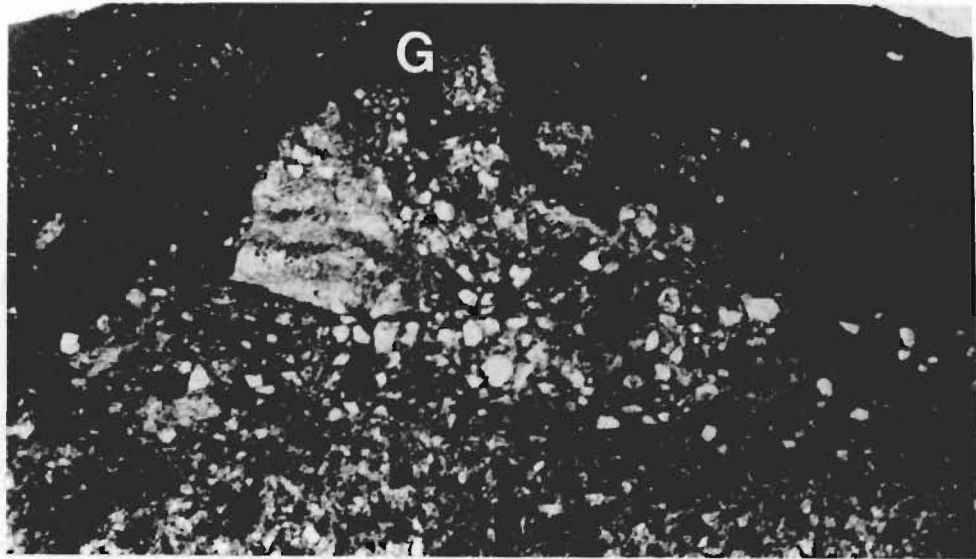
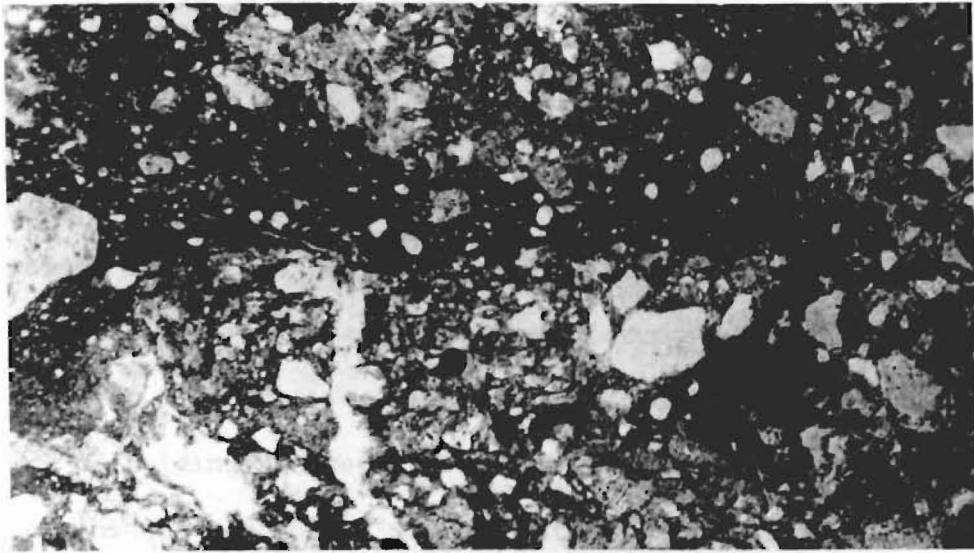
While deformation appears to have been largely ductile, microfractures subparallel and locally conjugate to the *mélange* microfabric do commonly occur. Sets of parallel microfractures may break sandstone/siltstone lenses into lozenges or "shear boudins", and locally crosscut matrix. This more brittle disruption may represent ongoing deformation of the *mélange* matrix under less fluid-rich (i.e. more highly dewatered) conditions. Figure 5.20 illustrates an intermediate case where a granule size block of laminated siltstone is cut by fractures while the matrix has deformed around it in a ductile manner.

One sample of laminar *mélange* matrix displays the minor displacement (<5 mm) of crosscutting calcite veins along zones of dark matrix (see figure 3.31b). This suggests that the *mélange* matrix was created, cut by veins and subsequently "readjusted" along minor movement planes parallel to the

Figure 5.18: Donation of intact detrital grains (dominantly quartz) to matrix from "disintegrating" sandstone.

Figure 5.19: Plucking of grains from sandstone margin and donation to matrix. Grain (G) appears to have been plucked along intersecting fractures and rotated into the matrix.

Figure 5.20: Sketch from polished slab: "block" of laminated siltstone fracturing while swirling matrix deforms ductilely around it.



fabric. The sense of movement in this case is down-to the-southwest.

5.5.3 Folding

Map relationships within and marginal to the Esk Head M \acute{e} lange do not strongly suggest major folding as an integral component of m \acute{e} lange formation. The zone displays extensive disruption by shearing. This, and subsequent dislocations within the m \acute{e} lange zone may obscure an early component of folding. However, it appears that if early major folding did occur, hinges have been "sheared out" and shear dislocations and subsequent flattening have acted as the primary agents in producing the fabric of the m \acute{e} lange zone. Minor folding does not appear to be accompanied by changes in bedding or m \acute{e} lange fabric attitude on a map scale, except in the case of Round Hill already discussed.

Minor folds:

A total of 57 minor folds were located and measured in the field (table 5.1). Most of these minor folds are believed to have accompanied shearing during m \acute{e} lange formation. One family of folds (group 1) are confined largely to olistostromal sequences and appear to be related to their emplacement. Minor folds are commonly noted as single folds in isolated outcrop, as folded "boudins" in m \acute{e} lange matrix, or as fold sets in highly veined sandstone/(mudstone). The orientation of fold axial planes (shown as poles to axial planes) and fold axes is shown in the accompanying stereoplots. Especially on smooth water-washed surfaces, hinge orientation is difficult to measure accurately and in some cases was not recorded as a result. Most minor folds appears to be steeply plunging.

An attempt to distinguish genetically related groups of minor folds is based on 1) their geometry and "tightness" in profile (after

Table 5.1. Minor Fold Data

No	"Family"	Lithology folded	Fold Axial Plane (strike/dip)	Fold Hinge (Azimuth/Plunge)	Fold Geometry	Tightness	Amplitude	Asymmetry? Sinistral Dextral Symmetrical
<u>Ashley Domain</u>								
1	4	sheared ss	100/80N	054/76	similar	Close	3 m	Dex
2	4	mélange matrix	050/57SE	099/50	similar	Tight	.75 m	Dex
3	4	mélange matrix	180/85E	?	similar	Open	5-10 cm	?
4	4	mélange matrix	160/90	160/30	similar	Isoclinal	.4 m	Sym
5	4	highly veined ss	180/90	180/50	similar	Isoclinal	.3 m	Sin
6	4	mélange matrix	165/80NE	152/49	similar	Isoclinal	5 cm	Sin
7	4	mélange matrix	010/75E	181/29	similar	Isoclinal	10 cm	Sym
8	4	highly veined ss	170/50E	149/23	similar	Isoclinal	.3 m	Sin
<u>Punanui Domain</u>								
1	1?	thin bedded ss	120/63N	?	parallel?	Close	.3 m	-
2	4	highly veined ss	012/54W	340/36	similar	Tight	5 cm	Dex
3	4	highly veined ss	030/70E	?	similar	Tight	.4 m	-
4	4	highly veined ss	054/70NW	014/61	similar	Tight	10 cm	Dex
5	4	highly veined ss	080/90	080/45	similar	Tight	3 m	Dex
6	4	highly veined ss	095/61N	?	similar	Tight	20 cm	-
7	4	highly veined ss	155/70NE	?	?	Open	5 cm	-
8	4	mélange matrix	130/70NE	118/46	similar	Tight	.3 m	Sin
9	1?	laminated assn	085/70N	?	parallel	Open	.75 m	-
10	1?	laminated assn	090/85S	?	parallel	Tight	.75 m	-
11	1	laminated assn	170/68W	156/06	parallel	Tight	50 cm	-
<u>South Branch Waipara Domain</u>								
1	3	"block" in mélange	150/75NE	?	similar	Isoclinal	1 m	Sym
2	3	"block" in mélange	120/80N	314/52	similar	Isoclinal	1 m	Sym
<u>Middle Branch Waipara Domain</u>								
1	2	medium bedded ss	065/40SE	092/20	parallel	Open	.5 m	-
2	2	medium bedded ss	030/65SE	050/36	parallel	Gentle	1 m	-
3	2-4?	thin bedded ss	060/75SE	080/52	parallel	Close	.4 m	Dex

Table 5.1. Minor Fold Data (continued)

No	"Family"	Lithology folded	Fold Axial Plane (strike/dip)	Fold Hinge (Azimuth/Plunge)	Fold Geometry	Tightness	Amplitude	Asymmetry? Sinistral Dextral Symmetrical
4	2-4?	thin bedded ss	153/75NE	136/50	similar?	Tight	1 m	Sin
5	4	sheared medium bedded ss	105/85N	077/78	similar	Close	10 cm	Dex
		<u>South Okuku Domain</u>						
1	"late"?	medium bedded ss	125/80N	114/44	"box"?	Tight	2 m	-
2	4	mélange matrix	180/40E	128/33	similar	Tight	20 cm	Dex
3	3	broken formation	120/65NE	093/44	similar	Isoclinal	3 m	Sym
4	2	highly veined ss	110/40S	110/0	parallel	Open	5 cm	Sin
		<u>Broken Hill Domain</u>						
1	1	laminated assn	110/60N	079/42	parallel	Isoclinal	5 m	-
2	2	laminated assn	070/55S	?	parallel	Close	20 cm	-
3	3	"block" in mélange	155/55E	120/39	similar	Isoclinal	15 cm	Sym
4	1?	medium bedded ss	000/80W	?	parallel	Tight	2 m	-
5	3	"block" in mélange	155/48W	?	similar	Isoclinal	.4 m	-
6	1	laminated assn	070/90	?	parallel	Tight	1 m	-
7	1	laminated assn	070/85N	273/57	parallel	Tight	1 m	-
8	1	laminated assn	075/90	?	parallel	Tight	.75 m	-
9	1	laminated assn	105/35N	315/19	parallel	Close	.4 m	-
10	1	laminated assn	010/90	?	parallel	Close	.75 m	-
11	4	highly veined ss	170/55W	215/45	similar	Tight	30 cm	Sin
12	4	highly veined ss	155/65E	118/52	similar	Tight	30 cm	Sin
13	4	highly veined ss	085/70E	296/54	similar	Tight	40 cm	Dex
14	?	thin bedded ss	145/50NE	039/49	similar	Tight	1 m	?
15	4?	mélange matrix	050/60N	?	similar	Tight	30 cm	?
16	4	mélange matrix	025/65E	038/27	similar	Tight	5 cm	Dex
17	4	mélange matrix	045/65SE	059/49	parallel?	Isoclinal	30 cm	Sym?
18	1	medium bedded ss	105/55S	?	parallel	Close	1 m	-
19	2?	thin bedded ss	045/48SE	?	parallel	Open	.5 m	-
20	3	"block" in mélange	095/90	?	similar	Isoclinal	1 m	Sym?

Table 5.1. Minor Fold Data (continued)

No	"Family"	Lithology folded	Fold Axial Plane (strike/dip)	Fold Hinge (Azimuth/Plunge)	Fold Geometry	Tightness	Amplitude	Asymmetry? <u>Sinistral</u> <u>Dextral</u> <u>Symmetrical</u>
		<u>Middle Okuku Domain</u>						
1	3	"block" in mélange	147/70NE	?	similar	Isoclinal	30 cm	Sym
2	3	"block" in mélange	085/80N	?	similar	Tight	20 cm	Sym
3	4	mélange matrix	005/90	005/30	similar	Isoclinal	20 cm	Sym
4	4	mélange matrix	150/75E	339/28	similar	Tight	30 cm	Dex
5	4	mélange matrix	108/76N	312/57	similar	Tight	15 cm	Dex
		<u>Esk Head I</u>						
1	2?	medium bedded ss	100/68N	066/54	parallel	Tight	1 m	Sin
2	4	highly veined ss	115/73N	308/37	similar	Tight	.5 m	Dex
3	4	highly veined ss	005/55W	292/54	similar	Tight	30 cm	Sin
4	4	highly veined ss	110/75N	073/65	similar	Tight	30 cm	Sin
5	0	medium bedded ss	015/65W	225/41	similar/disharmonic	Open	1 m+	-
6	0	medium bedded ss	045/70E	057/28	similar/disharmonic	Tight	1 m+	-
		<u>Esk Head II</u>						
1	2?	thin bedded ss	090/85S	245/78	similar	Close	.75 m	Sin
		<u>Esk Head III</u>						
1	2	sheared thin bedded ss	017/82W	300/80	parallel/box	Open	15 cm	-
2	3	broken formation	012/70W	?	similar	Tight	1 m	-
3	2	sheared thin bedded ss	045/90	045/30	parallel	Open	.75 m	-
4	0	chert	110/55N	020/55	similar/disharmonic	Open	1 m	-
5	2	thin bedded ss	145/65E	006/49	parallel	Open	20 cm	-
6	2	medium bedded ss	120/45NE	323/020	similar?	Gentle	15 cm	-

Ramsay, 1967 and Fleuty, 1964), 2) their relationship to regional fabric, 3) their relationship to local *mélange* and shear fabric, and 4) the lithology which they fold. Minor folds will be discussed below in the continuing manner of inferred reverse chronologic order. However the chronology of syn *mélange* folds is not clear. They may have formed at nearly the same time. The first group to be discussed (group 4) locally folds *mélange* matrix and appears to represent an ongoing process during *mélange* formation.

Asymmetric folding in highly veined sandstone and *mélange*, group 4:

A distinctive family of folds occurs within the highly veined sandstone lithology (see chapter 2) and within *mélange*. These folds are commonly asymmetric and are strongly related to local shearing (figure 5.21). Both sinistral and dextral asymmetry occurs. They range in amplitude from 5 cm to roughly 50 cm and display a "similar" geometry in profile. Axial planes are commonly steeply dipping. Curving hinges are seen locally, where exposure permits, and conjugate folding also occurs. Folds with curving hinges have been described from "shear zones" (Cobbold and Quinquis, 1980; Berthé and Brun, 1980) where fold axis curvature is a result of reorientation during progressive deformation. It has been suggested that "folds appear with their axes highly oblique to the stretching lineation and as they amplify, their axes rotate toward it" (Berthé and Brun, 1980).

The association of the highly veined sandstone lithology with large rafts of volcanics has been discussed in chapter 2. The abundant minor shears and shear related asymmetric folding within this highly veined lithology suggest that it occurs within shear zones of some type which have introduced local basement (i.e. volcanics) into the *mélange* zone. This relationship can be most clearly observed in the

Figure 5.21: Shear-related asymmetric folding within highly veined sandstone/(mudstone).

Figure 5.22: Tight folding in blocky *mélange* matrix.

Figure 5.24: Isolated fold hinge in "block" within *mélange*. Local *mélange* fabric orientation (indicated by arrow) is parallel to axial plane of folding.



western part of the Esk Head study area.

Axial planes of the asymmetric folds described are generally subparallel to local *mélange* fabric and regional fabric. Similar asymmetric folding occurs locally within *mélange* matrix, where it is associated with minor shears and folds the *mélange* fabric (figure 5.22). Fold axial planes remain parallel or subparallel to regional fabric however. Fold hinges are generally steeply plunging.

Sense of shear suggested by asymmetric folding:

Where folding plunges steeply and opposite senses of asymmetry occur, the relative sense of movement may not be immediately clear. The "separation-arc method" of Hansen (1971) may be applied to fold orientation data to establish a direction of movement (slip line) within a shear zone, idealized as a slip plane. In general, a shear zone can be expected to produce a family of folds whose hinges lie within the plane of the shear zone. In an ideal case, fold hinges of opposite asymmetry will be distributed into two opposing fields, situated on the slip plane, and separated by the slip line (figure 5.23). In practice, the two fields of opposite asymmetry are separated by an arc, and the slip line is regarded as the bisector of this arc. In this sense, the method attempts to use quantitatively the progressive rotation of fold hinges which occurs during shearing. Hansen (1971) stipulates that the method is only applicable where 1) folds of the same order and generation are used, 2) folded layers were planar prior to folding, 3) folds used have not been reoriented by later folding. Too little fold orientation data is available in this study to rigorously apply Hansen's method. The relationship of isolated fold data is not clear and isolated hinges may conceivably have been reoriented by later folding or faulting. However, stereoplots for individual domains indicate that many fold axial planes

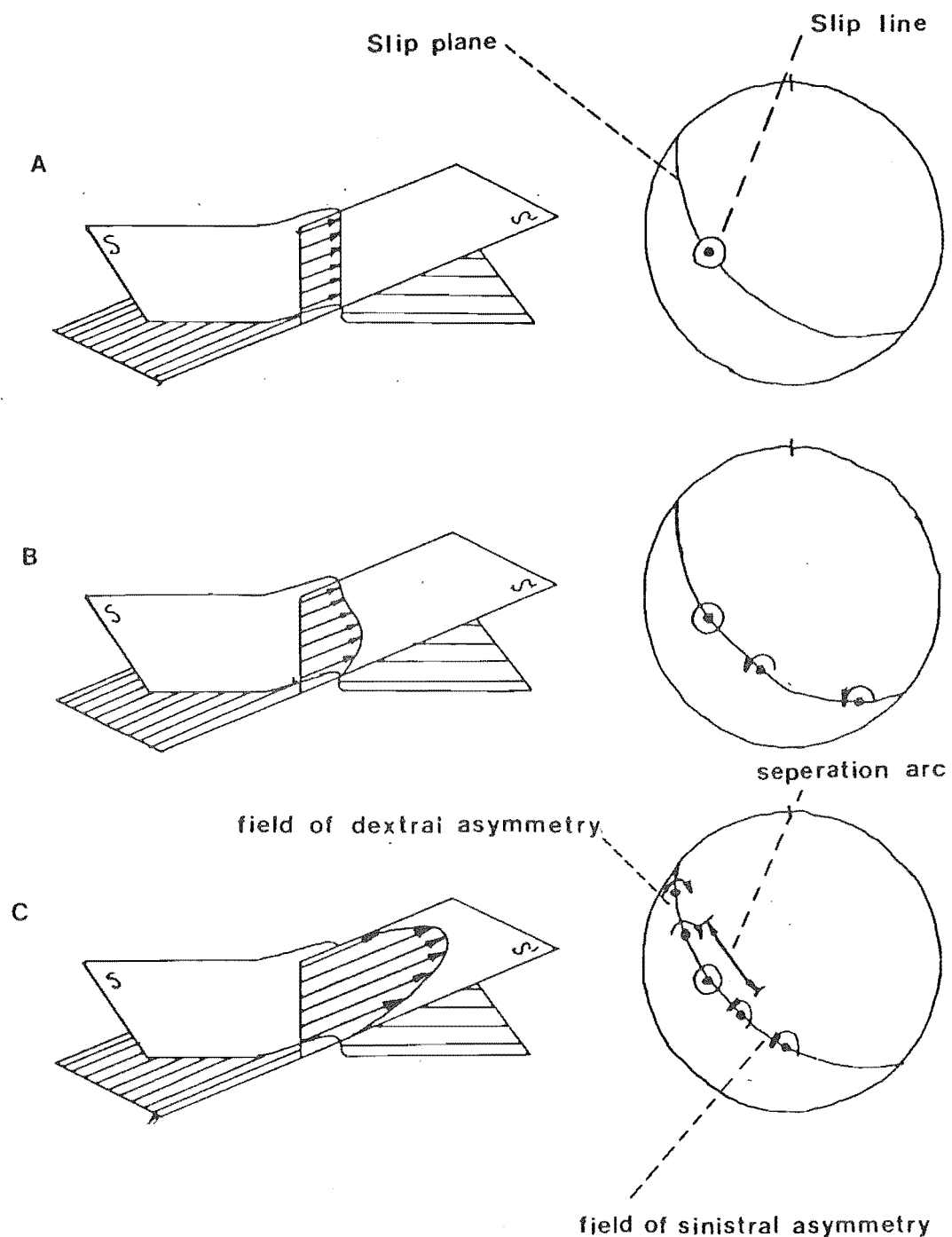


Figure 5.23: Schematic illustration of Hansen's "separation-arc method". Asymmetric folding in planar layer "S" and "lines of slip" (arrows) within slip plane " S^1 ". Fold hinges rotate during fold amplification (A to C) and define fields of dextral and sinistral asymmetry, separated by the "separation arc". (redrawn from Hansen, 1971)

are subparallel to regional fabric, and hence that hinges lie within the average fabric plane. This parallelism may have been enhanced by flattening. Overall, however, fabric and asymmetric folding are regarded as the result of a pervasive shearing process which is intimately connected with the genesis of the *mélange* zone. In this sense, the isolate folds of group "4" might be used in a semi quantitative way to at least suggest a sense of shear for the Esk Head *Mélange*. While fold hinges used may not be related to the same local shear zone, they are regarded as products of the same overall shear regime which has produced the systematic fabric observed.

The distribution of fold hinges about the average fabric plane is shown in the stereoplots for each domain. The consistent distribution of hinges of clockwise or dextral asymmetry in a northwest field and anticlockwise or sinistral asymmetry in a southeast field suggests a southwest over northeast sense of shear within the Esk Head *Mélange*. Movement along a moderately dipping oblique line lying within the southeast quadrant is implied within individual domains. A composite plot was constructed by correcting hinge orientations for variation in average planar fabric (figure 5.4k). Average fabric for each domain was rotated until parallel with that of the Punanui domain and group "4" fold hinge data was reoriented accordingly. Data is reasonably well concentrated along a line of best fit subparallel to the average fabric and the resultant "separation-arc" suggests movement along a line oriented 087° plunging 49° east. Because the Esk Head *Mélange* has been reoriented by faulting and flexuring, this movement direction is considered to be very approximate and is only provided as some measure of the "obliqueness" of movement within the average fabric "slip plane" or "slip zone".

Attenuated folds in isolated "blocks". group 3:

Several minor folds occur as isolated fold hinges defined by "blocks" within *mélange*. An example is shown in figure 5.24. Folds commonly display thickened hinges and attenuated limbs, as shown. They are generally isoclinal and symmetrical. Amplitude ranges from 15 cm to roughly 1 m. The local *mélange* fabric is always parallel to the axial plane of folding and hinges are steeply plunging. The origin of this family is unclear but they may represent isolated fold hinges a) whose limbs have been completely attenuated during shearing subparallel to regional fabric and which have been b) subsequently rotated during latter flattening into strict parallelism with the final fabric.

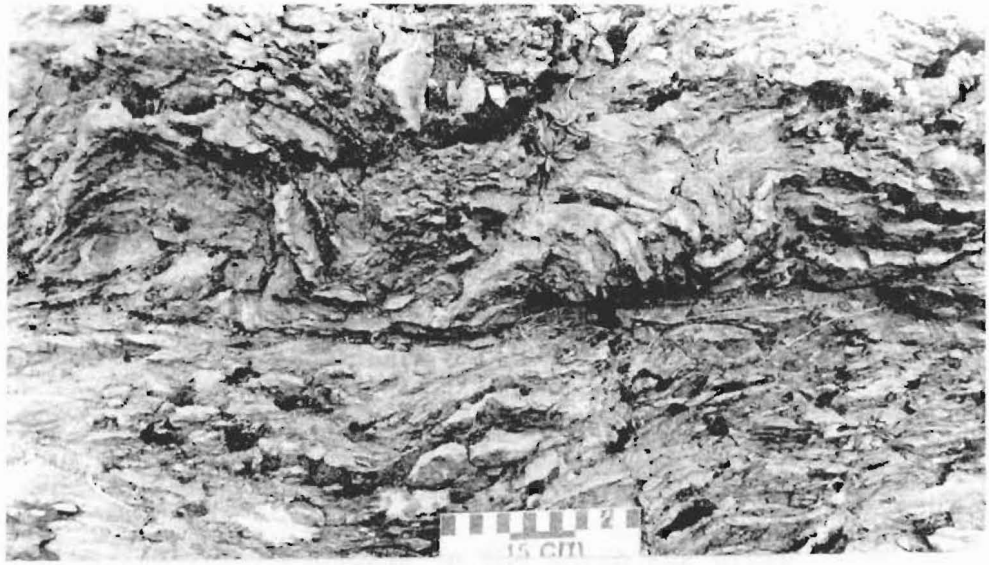
Open folding related to shearing, group 2.:

A group of related minor folds occur within the *mélange* zone and on its eastern margin. These are noted in thin to medium bedded, moderately disrupted units. These folds display a parallel to locally "box-folded" geometry, are gentle to open, and are an average of 15 cm in amplitude. They appear to occur within isolated 1 to 3 m zones parallel to the bedding/shear fabric of the host lithology. This gentle to open folding appears to be related to shear fabric in the sense that 1) hinges are locally "lopped off" by shears subparallel to the enveloping surface of the folding (figure 5.25), 2) early shears are folded while subsequent subparallel shear planes are not (figure 5.26). This evidence is not conclusive, but does suggest that this phase of gentle to open folding may be a local response of bedded units to shearing subparallel to bedding. Fold axial planes are oriented nearly perpendicular to fabric and folds plunge moderately (average roughly 50°).

At two localities, tight folding with a roughly 2 m amplitude is associated with, or refolds beds displaying open folding as described.

Figure 5.25: Folding in disrupted thin bedded sequence, truncated by shearing parallel to enveloping surface.

Figure 5.26: Open folding in sheared sandstone. Note presence of folded and unfolded shears.



This tight folding displays an attenuated (north) limb, an axial plane subparallel to the local fabric, and plunges at 50 to 70° to the south-east. Both folds display a sinistral sense of asymmetry. They are believed to be related to the same shearing regime which created the open folds and may result from the local progressive rotation and kinematic amplification of early fold hinges, during shearing (Cobbold and Quinquis, 1980).

A near vertical plunging sinistral fold occurs within disrupted thin to medium sandstone/mudstone in the North Esk River at L33/464 207 (figure 5.27). This fold displays a curving hinge. It is believed to be related to shearing in a similar manner to the two folds described above.

Syn melange structures in olistostromal sequences, group 1:

i) In chapter 3 "olistostromal sequences" were described from the eastern region of the Okuku study area. These sequences appear to have been formed by processes of debris flow, slumping, and related downslope movement of generally poorly lithified sediments. Particularly in structural domains which include these sequences (see Block Hill), a distinctive family of minor folds is noted. These folds are characterized by 1) a variable but generally parallel geometry, 2) a variable interlimb angle which is generally open to close, 3) a chaotic fold orientation locally and with respect to regional fabric, 4) a lack of associated shearing or brittle deformation, 5) a variable amplitude, from a few cm to roughly one metre. Folds occur within 1) the laminated lithologic association, 2) isolated clasts within the laminated association, 3) isolated thin sandstone beds or packets of beds in mudstone matrix. An example is shown in figure 3.16. Soft sediment, "slump folding" may be difficult to distinguish from later stage "tectonic" folding

(Woodcock, 1976). Distinguishing criteria listed by Helwig (1970) include 1) variable or irregular fold style, 2) the occurrence of secondary cleavages or foliation non parallel to fold axial planes, 3) associated ductile faulting, 4) chaotic structures not cut by open fractures or vein fillings, 5) folded clasts. The family of folds described appears to satisfy these criteria and are regarded as early, slump-related folds. Local variations in facing direction noted in the Okuku River, in the vicinity of M33/563 015 occur within a sequence which is believed to be slump-folded. The gravity-related emplacement of these olistostromal sequences is believed to be a facet of *mélange* formation, where the olistostromes are derived from a growing *mélange* and subsequently incorporated into the *mélange* (see chapter 6). In this sense, the folds inferred to be related to the gravity emplacement of these components are both syn *mélange* and pre *mélange*.

5.6 PRE MÉLANGE STRUCTURES, GROUP 0

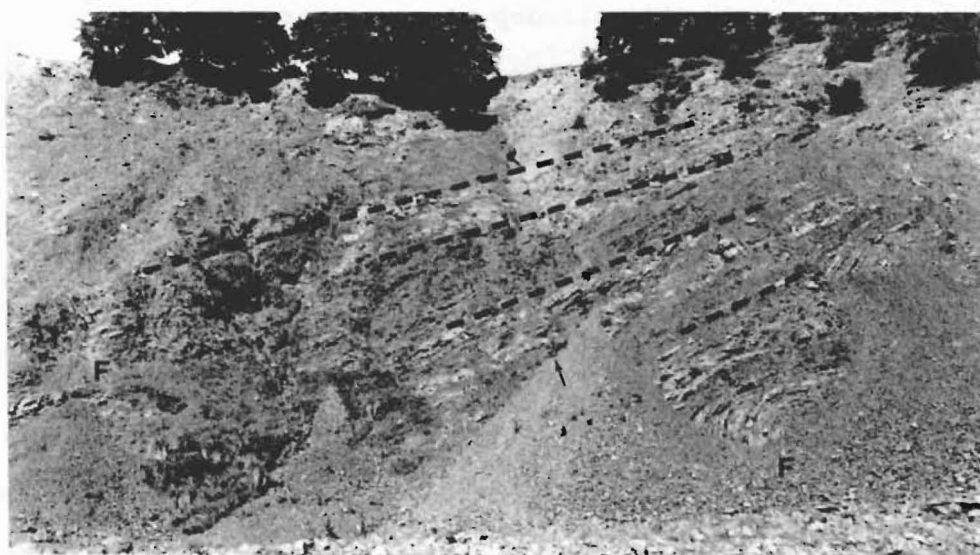
A few examples of deformation are inferred to have occurred prior to *mélange* formation:

Disharmonic gentle to open folding with an average amplitude of roughly 30 cm is noted in a few isolated exposures of bedded chert (e.g. Valley Stream L33.478 206). This folding also appears to bear no relationship to local or regional fabric and is believed to record an early (slump-related) deformation of these cherts.

An exposure of thin bedded sandstone/mudstone on the North Esk River (L33/403 202) displays larger scale disharmonic folding, apparently associated with "detachment surfaces" subparallel to bedding (figure 5.28). Similar well healed and subtle detachment surfaces are noted in a well exposed sequence of thin bedded sandstone/mudstone in the Okuku study

Figure 5.27: Steeply plunging sinistral fold in disrupted thin bedded sandstone/mudstone sequence. Note variation in hinge orientation (arrows) within successive folded layers.

Figure 5.28: Disharmonic folds (F) and "detachment surfaces" (dashed lines) within thin bedded sandstone/mudstone unit. (Backpack (arrow) indicates scale.)



area (M33/540 012) (see figure 2.11). Here these surfaces occur at roughly 10 m intervals and define "packets" of beds differing in orientation by 5 to 10 degrees across the surface. The orientation of these surfaces subparallel to bedding, their well healed and subtle nature and lack of associated brittle deformation suggests that they may be "syntaphral slide planes" (Carey, 1963). These detachment surfaces and associated disharmonic folding in the North Esk River locality are believed to represent localized early gravity-related movement within poorly, lithified thin bedded sequences.

Soft sediment microfaults in sandstones:

Several sandstone samples, collected from within the mélangé zone and from the eastern margin, display peculiar "discontinuity zones" in thin section. These are slightly curving to linear zones, less than 1 mm in width, with somewhat diffuse margins, distinguished by a concentration of clays and silt-size grains in an otherwise uniform fine to medium sandstone. The zones appear to be minor faults but have notably diffuse boundaries and display no fracturing of grains within or around them. The origin of these zones is questionable, but they appear identical to soft-sediment microfaults described and illustrated in photomicrograph by Thomson (1973) from the Tesnus Formation of Texas. Similar features have been noted in massive sandstones from the Esk Head subterrane to the east (Bradshaw, 1972). These soft-sediment microfaults are commonly cut by discrete later fractures.

5.7 SUMMARY AND DISCUSSION

Mélangé and shear fabric, folding and fault occurrence suggest the following sequence of events in the history of the Esk Head Mélangé (listed in reversed inferred order):

Post Mélange: Kaikoura

Mesozoic

- i) Block faulting: largely fault reactivation.
- h) Gentle flexuring and sinistral faulting.
- g) Rotation into steeply overturned attitude possibly accompanied by flattening.
- f) Local folding of "shear fabric": Round Hill anticline.
- e) "Early faulting" subparallel to fabric and "shear fracturing".
- d) Flattening subparallel to mélange fabric.

Syn Mélange:

Olistostromal sequences: chaotic folding during gravity-related emplacement.

- c) Shearing:
 - Large scale shearing in a southwest over northeast sense resulting in asymmetric folding (group 4).
 - Fragmentation and related processes:
 - localized gentle to open and tight folding related to shearing (groups 2 and 3)
 - continuing rupturing of bedding and mixing by shear fractures at a high angle to bedding
 - shearing subparallel to bedding including
 - 1) interbed shearing and associated minor conjugate shearing, 2) anastomosing shear sets.
- b) Initial compression subperpendicular to bedding resulting in boudinage rupturing of beds.

Pre Mélange:

- a) Syntaphral sliding and related folding in bedded sandstone/mudstone.
Disharmonic folding in bedded chert.
Soft sediment microfractures.

As Hsu (1968) suggests, the genesis of a mélange involves the two processes of fragmentation and mixing. Hsu notes the common coexistence in mélange (as seen in the Esk Head Mélange) of orthogonal-margin boudins created by extension, and "wedge-shaped tectonic inclusions" resulting from compressional shearing. The "complex history of extension and compression" implied is emphasized in the Franciscan mélange of California by Aalto (1981).

The sequence of events summarized suggests a framework of tectonic fragmentation and mixing in a changing or rotating stress regime dominated overall by shearing and followed by flattening, readjustment by faulting, and the later Mesozoic and Kaikoura effects described. The flattening noted may be related to two different phases of *mélange* history. Flattening may be in part, an immediate post *mélange* event, genetically related to the same processes which created the *mélange*. Chapter 6 presents a model of *mélange* generation in a subduction zone and subsequent incorporation in an accretionary prism. In this case, *mélange* flattening may reflect the compressive underplating of *mélange* material into the growing and landward-rotating prism under continued convergence. On the other hand, some of the flattening may have occurred later, during the same tectonic event responsible for the present steep overturning of the zone as a whole. This will be further discussed in chapter 6.

The "syntaphral slides" and related folds noted record the "slump-related" deformation of some bedded sequences, prior to incorporation in a zone of tectonic mixing. This may have occurred in a submarine fan setting (cf. Mutti and Ricci-Luchi, 1972) prior to tectonic dismemberment.

CHAPTER SIX

ORIGIN AND REGIONAL SETTING OF THE ESK HEAD

MÉLANGE

6.1 REVIEW AND INTRODUCTION

Mélange zones in many parts of the world have been extensively studied in the past fifteen years. Models for the origin of these zones range between two contrasting end members: 1) that of fragmentation and mixing by tectonic processes such as subduction or 2) mixing by sedimentary processes of slumping, gravity sliding or debris flow. In the case of large scale gravity sliding, the distinction between "tectonic" and "sedimentary" processes becomes blurred. Recent studies commonly begin by defining mélange in a non-genetic way as "a mappable, internally fragmented and mixed rock body containing a variety of blocks, commonly in a pervasively deformed matrix" (Silver and Beutner, 1980). This non-genetic approach evolved as studies began to reveal the complex combination of tectonic and sedimentary processes responsible for the final fabric of many mélange zones. As Hsu (1974) allowed, "sheared olistostromes" may be virtually impossible to distinguish from "tectonic mélanges". An example of the controversy in interpretation is provided by the "type" mélange in Anglesey, originally described by Greenly in 1919. Greenly regarded the zone as fundamentally a tectonic mélange or large scale "autoclastic breccia" while Wood (1974) provides evidence for a sedimentary origin.

The best documented example of a mélange zone as a fossilized subduction zone appears to be the Franciscan mélange and related zones in California (Hsu, 1968, 1971, 1973, 1974; Ernst, 1970; Blake and Jones, 1974; Cowan, 1974; Maxwell, 1974; Duffield and Sharpe, 1975; Cloos, 1982). A similar subduction-related origin is postulated for the Uyak mélange of Ala:

(Moore and Wheeler, 1978), the Trondheim mélange of Norway (Horne, 1979) and for mélange associated with the Dun Mountain Ophiolite of New Zealand (Blake and Landis, 1973; Blake, Jones and Landis, 1974; Coombs et al., 1976).

The formation of tectonic mélange along discrete shear zones has been documented in a similar underthrusting environment (Pettinga, 1982) or in a setting of large scale overthrusting (Schultz, 1979; Bosworth and Vollmer, 1981).

Recent studies provide strong evidence that other mélange zones were created largely by processes of sedimentary mixing. Examples include the Lichi mélange of Taiwan (Biq Chingchang, 1971; Page and Suppe, 1981), the Kathikas and Moni mélanges of Cyprus (Robertson, 1977; Swarbrick and Naylor, 1980), the Casanova complex of the Northern Apennines (Naylor, 1981, 1982), the Dunnage mélange of Newfoundland (Horne, 1969; Kay, 1976) and the Vardar mélange of Yugoslavia (Dimitrijevic and Dimitrijevic, 1974, 1976).

Mélange zones are commonly regarded as having formed at or near continental margins and so record the complex tectonic history of such margins. Their interpreted mode of formation may suggest a wide range of tectonic settings. Convergent margin settings may include subduction-related tectonic mélanges and/or mélanges of sedimentary origin derived from subduction-associated highs. Mélange zones may be formed along transform plate margins, as postulated for the Masirah mélange of Oman by Moseley and Abbotts (1979). Sedimentary mélanges may also be produced at passive plate margins, such as described from the Northern Apennines by Naylor (1981, 1982).

6.2 ORIGIN OF THE ESK HEAD MÉLANGE

6.2.1 Sedimentary vs Tectonic Mixing

The Esk Head Mélange is a strongly tectonized and complex zone whose origin is not simple. The two end members mentioned provide contrasting working hypotheses for the origin of the Esk Head Mélange. These are

- 1) that the extensive mixing and complex "block and matrix" fabric of the zone are fundamentally the result of the gravity-related processes of submarine sliding, slumping and debris flow; that is that the zone is a large scale olistostrome (Abbate *et al.*, 1971, Hoedemaker, 1973) or
- 2) that the zone is basically a "tectonic mélange" which has fragmented, mixed and incorporated various lithologies of different ages in the process of its formation.

The same fundamental problem has been approached in the study of other mélange zones and Wood and Schuster (1978) provide some basic criteria to aid in the distinction of "sedimentary" vs "tectonic" mélanges. These are: a) the nature of the top and bottom contacts, b) the presence or absence of a "ghosted" stratigraphy [plus relict bedding characteristics], c) the environment of initial deposition of components of the mélange, d) the importance of soft sediment deformation and injection structures, e) the armouring of clasts, f) penetrative deformation of the matrix, g) the physical nature of the deformational environment (e.g. metamorphic grade), h) evidence of a movement direction, i) the recognition of a tectonic overprint. The origin of the Esk Head Mélange will be evaluated on the basis of these criteria:

a) Nature of the top and bottom contacts

Olistostromes commonly occur within normal geologic sequences and display discrete upper and lower contacts. The lower contact may be unconformable to conformable. On the other hand, tectonic mélanges may be

expected to display gradational contacts in the same sense that ductile shear zones show maximum displacement and deformation in the zone centre, decreasing gradationally to the margins (Ramsay, 1980).

No unconformable or bedded relationships are observed at the margins of the Esk Head Mélange. Rather, both the southwest and northeast margins show a gradational change from a pervasively deformed block and matrix fabric within the mélange zone into subterrane on either margin, characterized by sheets of relatively intact lithologies separated by thin zones of blocky mélange (see geologic summary map). Within the Esk Head Mélange subterrane to the northwest, Bradshaw (1972) recognized these thin mélange zones as tectonic slides, locally superimposing Triassic rocks on Jurassic. The contacts of the Esk Head Mélange are regarded as gradational and suggestive of formation of the mélange in a tectonic zone of some type.

- b) Presence or absence of "ghosted" stratigraphy (plus relict bedding characteristics)

Despite the extensive mixing involved in sliding, slumping and debris flow deposition, large scale olistostromal deposits commonly record successive emplacement events as vague layering. Successive contributions of individual, local highs to the olistostrome may be recorded in the lithologic composition of individual layers or zones. The Lichi mélange of Taiwan, for example, displays colour banding on a scale of 1 to 10 m, showing both parallel and locally channeled relationships and discontinuous layers of detrital serpentinite within its fabric (Page and Suppe, 1981). Similarly, the Kathikas mélange of Cyprus displays colour banding and associated clast size variations, local channels, and inverse graded beds capped by chalk deposition, all preserved within a dominant block and matrix fabric.

On the scale of the Esk Head Mélange overall, no lithologic layering, colour banding, nor any features suggestive of successive gravity-related emplacement events are noted. The fabric of the zone as a whole indicates an intimate and pervasive mixing of lithologies suggestive of tectonic processes. Olistostromal sequences described in chapter 3 are regarded as *components* of the mélange and their significance will be discussed in section 3 below.

b)i) "Bedding" characteristics related to large "block" emplacement.

Large blocks emplaced into a muddy matrix purely by gravity sliding may be expected to display "aprons" of associated breccia confined to the sides and top of the block only, with emplacement-related structures confined to sediment at the base of the block. This emplacement effect is described from blocks in the Casanova olistostrome (Naylor, 1982) and from slide-emplaced pillow lavas (Bailey and Holliday, 1963). This effect has never been observed surrounding rafts mapped in the Esk Head Mélange.

c) The environment of initial deposition of components of the
mélange

The characteristics of sandstone/mudstone sequences described from the Esk Head/Okuku area are compatible with deposition in a submarine fan setting (see chapter 2 - Summary). Volcanics and associated chert and limestone could be the upper part of oceanic basement, and associated sedimentary cover, on which the fans were deposited. Blocks of these lithologies (sandstone/mudstone, volcanics, limestone and chert) may have been derived from an uplifted source or sources and mixed by sedimentary processes. However, a model involving their tectonic dismemberment and mixing in a subduction zone accommodates their presence in the Esk Head Mélange in a more direct and simple manner. The significance of the polymict conglomerate and related lithologies within this setting will be discussed below.

d) The importance of soft sediment deformation

Small scale features strongly suggestive of extensive soft sediment deformation have been described from olistostromal and slump-related deposits (Morris, 1971, Hoedemaker, 1973, Rupke, 1976, Naylor, 1981, 1982). These include 1) abundant folded clasts and related "slump balls", 2) extensive chaotic folding locally displaying a) load casted lower fold limbs or b) folded layers wrapping around neighbouring boudins or c) the draping or ponding of overlying sediments by folds, 3) "ploughing" of angular boudins into underlying units, locally with associated flame structures, 4) injection of matrix into fractures in "blocks", 5) soft sediment "pullapart" of sandstones, 6) partial homogenization of sandstone, mudstone sequences, 7) imbrication of clasts, 8) abundant sandstone dykes, 9) preservation of delicate sedimentary features such as ripple marks or flute casts, 10) armoured clasts. Some of these features have been noted in the "olistostromal sequences" described in chapter 3, however these sequences are *components* of the *mélange* and not typical of the zone as a whole. (NO armoured clasts were located anywhere within the Esk Head/Okuku area). The Esk Head *Mélange* is dominated by blocky *mélange* matrix which displays virtually none of the slump-related soft sediment deformation features listed above. It might be argued that such features were present initially and have been obscured by later shearing. However, enough intact sequences have been examined to suggest that extensive soft sediment deformation has been confined to the "olistostromal sequence" components of the *mélange*.

The deformation of sandstone and sandstone/mudstone sequences within the Esk Head *Mélange* does appear to have occurred while sediment was in widely different states of lithification. Style of boudinage within sandstone beds varies from gentle pinch and swell suggestive of semi-plastic extension, to discrete orthogonal fracturing suggestive of brittle deformation.

Mélange fabric appears to record an overall semi-plastic style of deformation accompanied by the ongoing effect of brittle shear fracturing. Individual mélange sections display the intimate mixing of both brittle-fractured and semi-plastically deformed "blocks". Volcanics commonly display deformation by brittle shearing and only record semi-plastic deformation where extensive early alteration to chlorite has taken place.

The dark muddy matrix of the mélange is locally injected into fractures in all lithologies on a variety of scales. The matrix in this case appears to have behaved as a fluid-rich medium which locally has achieved high pressures during deformation.

The deformation style described above is compatible with the compression and shearing, accompanied by sediment dewatering, experienced by sediment entering the upper parts of a subduction zone. In such a regime, sandy sediment may dewater initially to a semi-plastic state and be deformed within a fluid-charged mud. Moreover, sediment in various states of water saturation may be delivered to the subduction zone depending upon local permeability barriers. Sediment entering the upper subduction zone may rapidly dewater along shear fractures and subsequently undergo increasingly brittle-style deformation. At the same time, zones of both fluid-charged mud or ductile, water-saturated sandstones may be temporarily preserved by local permeability barriers while brittle deformation continues nearby.

Soft sediment deformation in the form of syntaphral slides and associated disharmonic folds is regarded as pre-mélange structure. This may represent local slumping in a submarine fan setting prior to incorporation in the mélange.

f) Penetrative deformation of the matrix

"Block"/matrix relationships within the Esk Head Mélange suggest ongoing ductile flow of the matrix around semi-plastic to rigid "blocks", with onset of brittle shear fracturing in the matrix possibly accompanying later dewatering. The pervasive deformation style preserved in the matrix appears to be intimately connected with the genesis of the mélange and not merely a fabric imposed on an already mixed block and matrix lithology.

g) Physical nature of deformational environment (metamorphic grade)

Both "blocks" and matrix within the Esk Head Mélange and the margins of the zone, demonstrate consistently low metamorphic grade, i.e. zeolite facies. This situation might have been produced by the creation of the Esk Head Mélange as an olistostrome and subsequent low grade burial metamorphism. However, metamorphism has been demonstrated to be an ongoing effect accompanying the production of the mélange. Metamorphic effects are believed to be more consistent with contemporaneous deformation and metamorphism in the upper reaches of a subduction zone. A recent study of the matrix mineralogy in the Franciscan mélange of California suggests very similar conditions of metamorphism to those suggested for the Esk Head Mélange; that is, temperature between 100 and 250°C and pressure between 2 and 8 kb (Cloos, 1982).

h) Evidence of a movement direction

An overall southwest over northeast sense of movement is suggested within the Esk Head Mélange (Chapter 5 - Structure). The significance of this sense of movement depends entirely on the tectonic history invoked to achieve the present steeply overturned attitude of the zone. If, however, the fabric of the zone is rotated about strike and restored to a near horizontal attitude, the movement direction could be interpreted in the light of either 1) gravity sliding down an northeast-facing slope or 2) underthrusting in a southwestward dipping subduction zone. If a

mechanism of near-vertical emplacement of the *mélange* is postulated, the southwest over northeast movement direction may reflect the nature of this emplacement.

i) The recognition of a tectonic overprint

The basis of this criterion is: Can the structural fabric of the *mélange* zone be directly related to its genesis, or is the fabric purely an "overprint" of an already-mixed rock body? In the case of a "sheared olistostrome", initial fragmentation and mixing, and fold structures related to "block" or raft emplacement, need bear no relationship to the final structural fabric of the zone. This is true, for example, in the case of large scale slump deposits in the southwest Pyrenees (Rupke, 1976) and in the Vardar *mélange* of Yugoslavia (Dimitrijevic and Dimitrijevtic, 1974, 1976).

The Esk Head *Mélange* displays a pervasive shear fabric. Shearing is a key element in the initial fragmentation and continued mixing of lithologies within the zone. In other words, the fundamental structural fabric of the *mélange* zone (notwithstanding a late-stage flattening overprint) is intimately related to the genesis of the zone. The axial planes of small scale folds display a strong parallelism with local and regional fabric throughout most of the *mélange* zone and suggest that folding is related to fabric and hence to *mélange* genesis. The notable exception, where fold data is widely divergent from overall fabric, is displayed in an eastern "olistostromal" component of the *mélange* (Block Hill domain).

Summary

Regarded in the light of these criteria, features of the Esk Head *Mélange* suggest that it is fundamentally a tectonic *mélange*. Suggestions of olistostromal components within the *mélange* have been raised in this

section, and will be treated more fully following a discussion of the postulated tectonic setting of the zone.

6.2.2 Tectonic setting of the Esk Head Mélange

The Esk Head Mélange occurs within the Torlesse, apparently as a complex tectonic contact between the Late Carboniferous to Late Triassic Rakaia subterrane to the southwest and the Late Jurassic to Early Cretaceous Pahau subterrane to the northeast (Bradshaw *et al.*, 1980). Local sequences within the Esk Head Mélange and subterrane young to the southwest within an overall framework in the Torlesse of increasing age to the southwest. This regional pattern may have been produced in a tectonic framework of 1) large scale gravity sliding or 2) subduction and related deformation; possibly followed by tilting into the present near vertical attitude widely seen in the Torlesse.

It is considered unlikely that a zone on the scale of the Esk Head Mélange could have originated as a "friction-carpet" or décollement zone beneath a single gravity nappe. A gravity sliding model involving the successive, subhorizontal emplacement of sheets or nappes of sediments and volcanics, with attendant shearing along slide planes, might be postulated. The pervasive and systematic shear fabric and extensive mixing within the Esk Head Mélange are difficult to reconcile with this model however. Neither the style nor degree of deformation increases in the vicinity of large "rafts" mapped within the mélange zone and they are not thought to be gravity-emplaced. Rather the "rafts" are regarded as components of a zone which originated in a regime of larger scale deformation.

While a subduction model may be overworked with regard to the genesis of mélange zones, the sequence of fragmentation, mixing and

deformation events suggested by the structural fabric (summarized chapter 5 - Structure) does appear to fit a model of subduction tectonics. Studies of modern and ancient subduction zones suggest that these are regimes of large scale underthrusting. Sediments and possibly the upper parts of basement are scraped off the descending plate and accreted to the upper plate. This may result in the growth of a highly deformed "accretionary prism" above the trench. Continued addition of material at the trench may result in the landward tilting of the growing prism (Karig and Sharman, 1975).

While deformation at the trench is not well understood, it appears that sediment 1) is initially downbent and compressed during convergence, where it 2) enters a "master shear zone" and in the process of being accreted to the upper plate 3) undergoes shearing reflecting underthrusting and then 4) leaves the shear zone as it becomes part of the accretionary prism and may be 5) subsequently flattened during landward rotation of the prism under continued plate convergence and 6) subject to faulting readjustments of the accretionary prism (Karig and Sharman, 1975; Seely, 1977; Moore and Wheeler, 1978). A zone resulting from such a sequence of events could be expected to display the effects of iterative shearing. This idealized sequence of events is distinctly similar with those described from the Esk Head Mélange.

Alternatively, the Esk Head Mélange may have been generated in steeply dipping zone dominated by transcurrent movement and attendant shearing. The present steep dip of mélange, shear fabric and minor fold hinges might have been achieved in such a zone with little subsequent rotation. However, if shearing occurred in a reasonably homogeneous medium and the sense of movement was consistent, folds of only one asymmetry, sinistral or dextral would be created in such a regime.

Extensive refolding along gently plunging axes could mix hinges of different asymmetry, but such a fold episode is not observed in the Esk Head/Okuku area. The occurrence of both sinistral and dextral fold hinges within the same fold generation suggests that deformation did not occur in a simple transcurrent regime.

If the genesis of the Esk Head *Mélange* is indeed related to subduction, the southwest over northeast sense of shear may imply a southwestward dipping subduction zone. (It should be noted that the formation of relatively thin *mélange* zones associated with obduction and landward verging overthrusting has been described (Bosworth and Vollmer, 1981) and would imply subduction in the opposite direction. This appears unlikely in this case however.) The present steeply overturned attitude of the *mélange* zone fabric may have been initiated as the landward tilting of an accretionary prism associated with a westward dipping subduction zone. Extensive landward tilting of this type is described from several studies of modern and ancient subduction zones (Karig and Sharman, 1975; Moore and Wheeler, 1978; Moore and Karig, 1980). The flattening event noted in the Esk Head *Mélange* may be in some way related to this progressive rotation. Final readjustment of the overall fabric to a steeply overturned attitude may relate to a later compressional orogenic event (see regional setting below).

The "early faults" described in Chapter 5 (Structure) are regarded as adjustments to an already-formed *mélange*. Since the sense of movement on the "early faults" is not clear, their significance is uncertain. A speculative comparison may be drawn with the setting of Nias Island (Karig *et al.*, 1980) where two groups of faults are mapped subparallel to the regional fabric. The first group is a high angle reverse fault system accommodating landward tilting of the accretionary prism. The second

group is a series of strike-slip splays off a major strike-slip fault system. These represent decoupling and resolution of oblique convergence into a dextral strike-slip system landward of the trench. No structures suggestive of strike-slip movement are associated with the "early faults" of the Esk Head Mélange, however. It appears more likely that they are readjustments of the mélange related to its final emplacement.

6.2.3 Olistostromal sequences in the Esk Head Mélange

Evidence presented in the foregoing sections suggests that the Esk Head Mélange is primarily a tectonic mélange which may have been created in the upper regions of a westward dipping subduction zone. However "olistostromal sequences" have been described from the eastern regions of the mélange and it is clear that a model of the Esk Head Mélange must accommodate a component of sedimentary mixing.

It has been suggested that the Franciscan mélange of California incorporates olistostromal components of "recycled material" derived from a growing tectonic mélange (Maxwell, 1974; Cowan and Page, 1975; Gucwa, 1975; Page, 1978; Aalto, 1981). The role of olistostromes in the genesis of the Franciscan is summarized in the model of Page (1978) (figure 6.1). Page suggested that mélange material is derived from an outer arc ridge within a growing accretionary prism and transported and deposited in the trench as an olistostrome. Here it is reinvolved in subduction and subsequently reincorporated into the growing mélange. A similar model may explain the occurrence of olistostromal sequences as components of the Esk Head Mélange. A recent analogue of this model is described from the Sunda Arc by Moore et al. (1976). Here the Bassein slide, up to 1 km in thickness and 4000 km^2 in total area and containing blocks up to 360 m thick, has been derived from the Sunda Trench wall. Moore et al. suggest that, assuming continuity of present plate motion, the slide will again be

partially accreted to the Sunda sedimentary arc and possibly partly subducted.

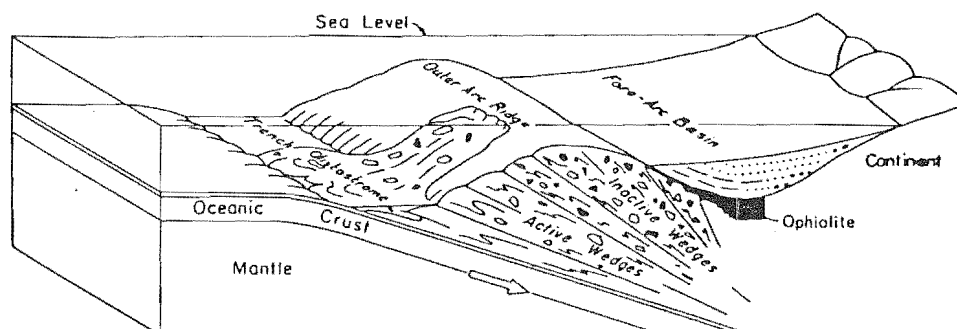


Figure 6.1. Hypothetical role of olistostromes in genesis of the Franciscan. Black fragments are older constituents carried in olistostromes, re-involved in subduction, and incorporated into successively younger wedges during continued underthrusting. Ordinary, less distinctive constituents are dispersed and reincorporated into mélanges in the same way. from Page (1978)

The Esk Head Mélange may be divided into two broadly contrasting regions, western and eastern. The western region is characterized by the presence of abundant large rafts of volcanics, pervasive shearing, and ubiquitous "shear polishing" along anastomosing shear surfaces, and is dominated by blocky to laminar mélange matrix. Polymict conglomerate and the laminated lithologic association occur only as relatively small, isolated blocks within mélange in this region. There is a suggestion of a transitional increase in the size and frequency of olistostrome-related components of the mélange eastward into the eastern region. Here volcanic blocks are generally smaller and olistostromal sequences occur as key components of the mélange.

The olistostromal sequences described in Chapter 3 are characterized by the presence of 1) rounded to angular polymict conglomerate, interpreted as debris flow deposits, 2) a laminated lithologic association, interpreted as "background" deepwater sediment locally displaying the effects of slumping, 3) a "disorganized" association, interpreted as localized debris flow deposits, and, 4) a bedded breccia association, postulated to result from the downslope movement of poorly lithified water-rich sandstones. Small scale folding within olistostromal sequences is commonly chaotic and is believed to be slump-related. The presence of localized zones of blocky *mélange* matrix within these sequences may be in part related to fragmentation during downslope movement. However, blocky *mélange* overall is regarded as the product of tectonic fragmentation and mixing.

Three main olistostromal sequences are recognized in the eastern part of the Okuku study area and are 75 m, 800 m and roughly 1000 m in thickness. Westward of these sequences and within the Esk Head study area, polymict conglomerate and bedded breccia lithologies similar to those described from the olistostromal sequences occur as isolated blocks in *mélange* ranging in size from 2 to 10 m². These may represent "scraps" or dismembered elements of other originally comparable olistostromal sequences. Isolated occurrences of the laminated association are also noted within the Esk Head study area. The distribution of olistostromal sequences and isolated blocks of component lithologies is shown in figure 6.2.

The composition of the polymict conglomerates within the olistostromal sequences mirrors that of the *mélange* itself, in that they contain sandstone, mudstone, metavolcanics, limestone and chert. The conglomerates could well have been derived from erosion of uplifted portions of the *mélange*, and transported downslope as debris flows. Some contribution

of material to these debris flows from high energy, shallow water sources is suggested by the presence of well-rounded boulders within the conglomerates.

Deposition of olistostromes and associated lithologies need not have been confined to the trench itself but may also have occurred in localized ponded basins developed along the lower trench slope. Deposition of debris flow deposits and turbidites in slope basins of this type has been documented, from a setting analogous to this overall model, on Nias Island (Moore and Karig, 1976). Slope basin deposits of this type may be tectonically dismembered and incorporated into the *mélange* zone as a whole by ongoing thrusting and deformation during continued rotation of the accretionary prism.

The distribution of olistostromal elements within the Esk Head *Mélange* may then be the result of either 1) deposition in trench slope basins across the developing *mélange* zone and subsequent dismemberment, or 2) successive events of deposition at the trench, and immediate incorporation into the *mélange* zone. The confinement of the larger scale olistostromal sequences to the eastern margin of the *mélange* zone may argue for a trench-olistostrome origin for them.

6.3 REGIONAL SETTING

6.3.1 Relationship with subterrane to the northeast

Bradshaw (1973) has noted the similarity in deformation style between tectonic slides mapped in the Esk Head subterrane to the northeast and the *mélange* zone itself. In the context of the model presented, these slide zones may be regarded in two different ways. On one hand, the Esk Head subterrane might be regarded as an integral, less highly deformed,

portion of the accretionary prism. In this case, the tectonic slides may represent relatively discrete thrusts which have "sheared off" slices of volcanic basement and overlying sandstone/mudstone sequences from the downgoing slab in the continuing process of underthrusting during subduction. The diminished role of *mélange* formation overall may reflect changing conditions of convergence and subduction, for example a slowing subduction rate.

On the other hand, the Esk Head subterrane may represent a large scale gravity slide complex derived from some portion of the accretionary prism, emplaced on its eastern margin, and subsequently rotated into its present steeply inclined attitude. In this case, the tectonic slides would represent major *décollement* or gravity slide surfaces separating gravity slide sheets. The strong parallelism of the Esk Head subterrane with the *mélange* zone itself, similarity in deformation style, and intimate association of the *mélange* zone and its subterrane argue for a strongly related genesis. The Esk Head subterrane is regarded as a less highly deformed eastern portion of the same accretionary prism which contains the Esk Head *Mélange*.

6.3.2 Age relationship of *mélange* elements

Fossils ranging in age from Late Triassic to Late Jurassic are contained by elements incorporated in the Esk Head *Mélange*. In the model envisaged, the Late Triassic elements of the *mélange* represent fragments of local oceanic basement, dismembered and mixed in the subduction zone with sandstone/mudstone sequences of Jurassic age. Late Triassic *Monotis* limestones of the *mélange* zone are believed to be basement-related (chapter 2). Siltstones collected in this study from bedded sandstone/mudstone elements of the *mélange* have yielded spores which are certainly Jurassic, and may be Early to Middle Jurassic in age (J.I. Raine, pers. comm., 1982) (see Appendix II). Slope basin deposits ("olistostromal

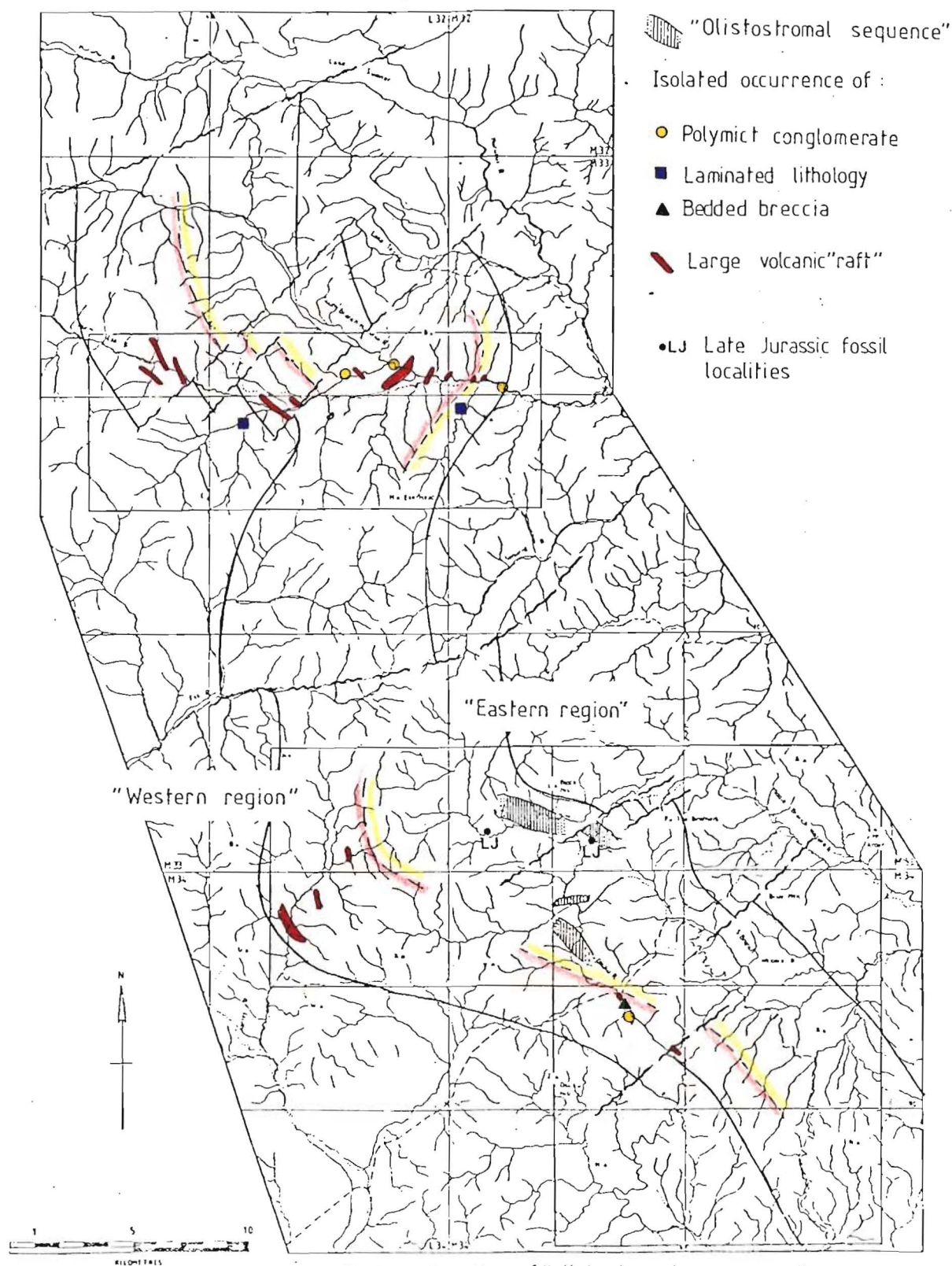


FIGURE 6.2 : Location of "olistostromal sequences"

sequences" and related sediments) incorporated within the *mélange* zone might be expected to be the youngest elements of the zone, and the loose boulders which have yielded Late Jurassic fossils may be derived from these. The proximity of Late Jurassic fossil localities to the "olistostromal sequences" mapped is shown in figure 6.2.

6.3.3 Postulated history of the Esk Head *Mélange*

This discussion of the origin of the Esk Head *Mélange* accepts the hypothesis (Bradshaw et al., 1980) that the older Torlesse rocks of Permian and Triassic age, the Rakaia subterrane, were accreted and consolidated by the end of the Triassic, and that a new trench/subduction zone was established to the east. The Haast Schist terranes and the Rakaia subterrane formed a folded, metamorphosed and progressively uplifted (Adams and Robinson, 1977) inner margin to subsequent accretion. During the Jurassic, localized shallow marine to non-marine sedimentation took place on uplifted portions of the already-consolidated Rakaia subterrane, e.g. Clent Hills (Oliver, 1977).

The history of the Esk Head *Mélange* will be discussed in terms of two alternative models. The first involves genesis of the *mélange* in a subduction zone and subsequent landward tilting. The second involves tectonic emplacement of the Esk Head *Mélange* as a steeply dipping zone landward of the trench by subduction-generated upward movement (figure 6.3). The fundamentals of model 2 have been suggested to me by J.D. Bradshaw (pers. comm., 1982).

Mechanism of models

Model 1: In the first model, subduction is postulated to have started in the Jurassic, and the Jurassic is dominated by *mélange* formation (Esk Head *Mélange*) in the upper parts of the subduction zone. During subduction,

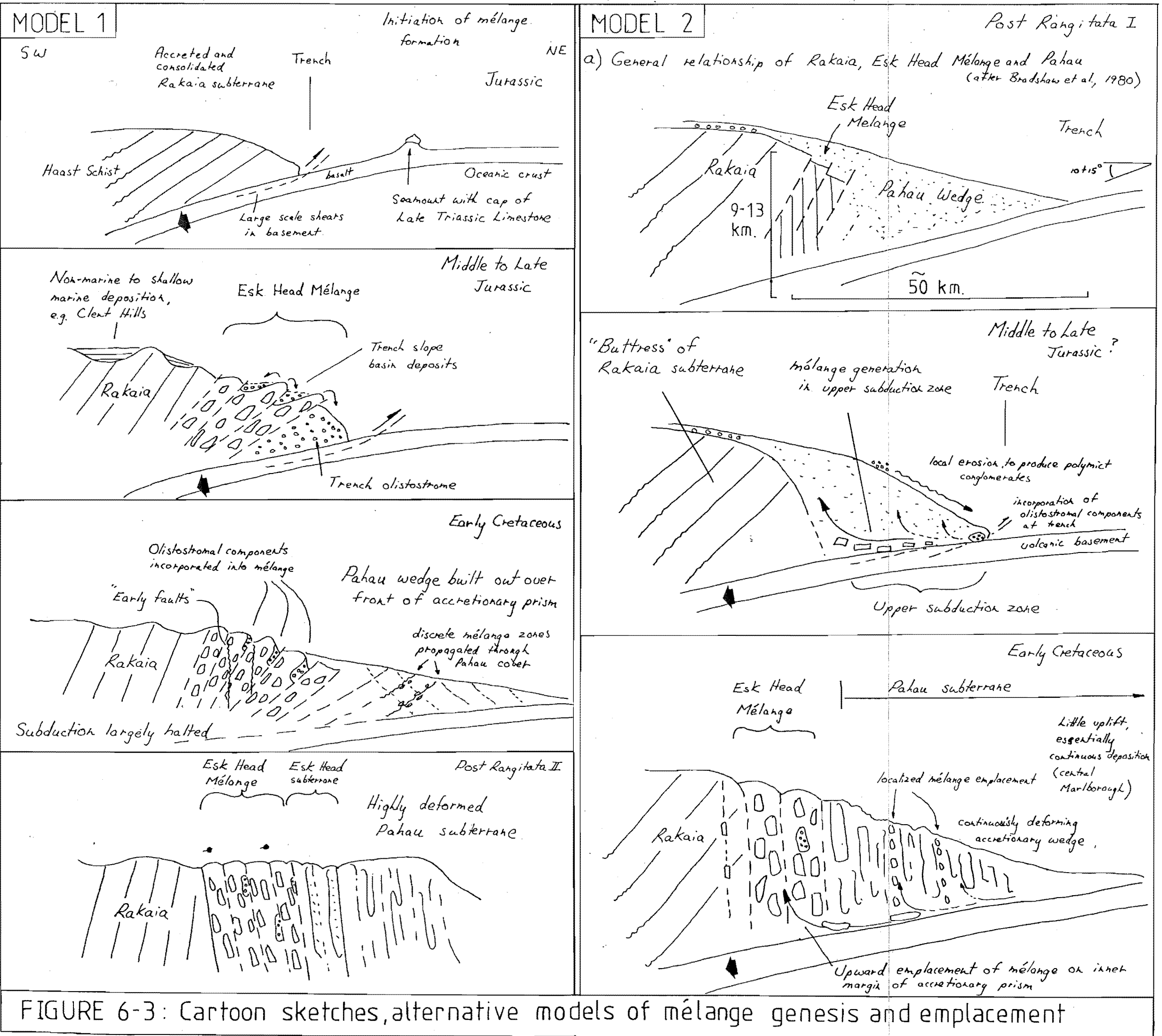


FIGURE 6-3: Cartoon sketches, alternative models of mélangé genesis and emplacement

volcanic basement with local caps of Triassic limestone was delivered to the subduction zone, sheared off the downgoing slab, and mixed with recently deposited Jurassic sediment. Material supplied to the trench may be represented by a high volume of mud, with localized submarine fan deposition of sand into the trench. The high volume of mud is available as a "muddy matrix" in *mélange* formation. At this time, the presence of a thin sedimentary cover in the subduction zone may have resulted in the propagation of large scale shears within the volcanic basement. This may explain the incorporation of large rafts of volcanics at an early stage of *mélange* formation, now represented in the western region of the Esk Head *Mélange*.

The growing *mélange* was accreted onto the growing and landward-rotating accretionary prism. By the Late Jurassic, sufficient relief may have developed on the growing accretionary prism that trench slope basins may have begun to form. Parts of these may be represented by "olistostromal components" incorporated into the continually deforming *mélange*. Deposition of olistostromes and incorporation into the *mélange* zone may also have occurred in the trench.

Subduction is postulated to have slowed in the Late Jurassic and generally halted by the Early Cretaceous, permitting the deposition of the Pahau wedge of sediments (Bradshaw *et al.*, 1980) largely off the front of the now relatively inactive accretionary prism. Intermittent resurgences of subduction may have resulted in the formation of smaller scale *mélange* zones within the Pahau cover, e.g. *mélange* bodies in the Seaward Kaikoura Range (Andrews *et al.*, 1976; J.D. Bradshaw, pers.comm. 1983).

Compression associated with the Rangitata II orogenic event

(Bradshaw *et al.*, 1980), toward the end of the Early Cretaceous, may have been responsible for the overturning to the southwest of the already steeply dipping *mélange* zone contained within the accretionary prism. This event may also have contributed to the flattening noted in the *mélange* zone. Sinistral fault offsets and related flexuring of the *mélange* zone may also be related to this episode of deformation.

The late history of the *mélange* zone is common to both models. *Mélange* formation in the Esk Head *Mélange* had ceased completely by the time of emplacement of northeast-trending, pre Upper Cretaceous dykes related to the Mandamus syenite to the east. Late stage Kaikoura deformation of the Esk Head *Mélange* and margins is dominated by block faulting, characterized by extensive fault gouge, largely along pre-existing faults, in the Esk Head/Okuku area.

Model 2: The postulated history of the Torlesse provided by Bradshaw *et al.* (1980) suggests that deposition of Pahau sediments began after Rangitata I on a Pacific-facing slope to the southwest of a newly established trench/subduction zone. If deposition of the Pahau wedge began in the Jurassic and continued into the Cretaceous, then it must be in part contemporaneous with formation of the Esk Head *Mélange*, and *mélange* formation is not related to a simple model of underplating as described. The location of the Esk Head *Mélange* landward of the trench and subduction zone suggests that it occurs as an "inner zone" related to subduction in a more complex way. In this case, the Esk Head *Mélange* might represent a major Pacific-verging thrust system, which when eroded, appears as a complex tectonic contact between the Rakaia and Pahau subterranean. However it is unclear how, in such a model, large slices of Triassic or older volcanics, inferred to represent basement, could have been incorporated in the *mélange*.

Cowan and Silling (1978) provide a model of subduction-driven upward flow of deeply buried material which rises into relatively shallow levels of the accretionary wedge at its landward margin (figure 6.4).

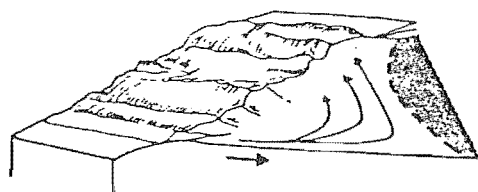


Figure 6.4. General kinematic model of accretion at subduction zones. Minor underplating occurs at the base of the trench slope and massive upward flow occurs in the interior of the accretionary prism. from Cowan and Silling, 1978.

This model accounts, for example, for the presence of high grade metamorphic rocks (blueschist facies) which occur in the easternmost, structurally highest levels of the Franciscan Complex of California.

Such a concept may be applied to the emplacement of the Esk Head M \acute{e} lange. Subduction may have resumed during the Jurassic, and was definitely active during the Early Cretaceous. The accreted and consolidated Rakaia subterrane acted as a "buttress" to deformation occurring within the accretionary wedge to the east. The Pahau subterrane represents an active and continuously deforming margin during this time. Formation of localized m \acute{e} lange zones within the Pahau accompanied this deformation.

Fragmentation and initial mixing of the Esk Head M \acute{e} lange began in the subduction zone, in the manner described in model 1. Olistostromal components may have been incorporated in the m \acute{e} lange from the trench.

Continual deformation and mixing occurred during movement along the shallow-dipping subduction zone, until the *mélange* was ultimately emplaced as a near vertical zone by upward movement at the landward margin of the Pahau wedge, against the "buttress" of the Rakaia subterrane. Little uplift occurred at the seaward margin of the Pahau wedge.

Zones of flow related to *mélange* emplacement may have resulted in the locally observed rounding of "blocks" in the *mélange* by plucking, as ductile matrix moved past brittle "blocks". A recent model of "flow *mélanges*" in the Franciscan of California (Cloos, 1982) suggests ongoing mixing during flow related to 1) size differences in "blocks" and 2) the plucking of "blocks" from the sides of "flow zones".

Discussion

Regional geologic problems relate to both models and include 1) the nature and duration of subduction and 2) the paucity of Early and Middle Jurassic sediments within the Torlesse.

If subduction occurred throughout the Jurassic, why is there no Jurassic subduction-related calc-alkaline volcanic arc in South Canterbury? The only volcanics seen are the calc-alkaline Mount Somers Volcanics in mid Canterbury which are early Late Cretaceous in age (Oliver, 1977, Oliver *et al.*, 1979). This may be related to the configuration of the subduction zone, the timing of subduction, or both. A very shallow-dipping subduction zone may have been established following the accretion of the Rakaia subterrane, whose presence may have essentially "flattened" the Benioff zone into a very shallow dip. This would result in the wide separation of a trench and subduction-related arc. The scale of separation involved is indicated by examples such as the North Island, New Zealand where a 200 km separation occurs (Hatherton, 1974), and the Aleutian

subduction system, where a 400 km separation exists (Karig and Sharman, 1975). In the context of the models provided, the presence of a shallow-dipping subduction zone might mean that Jurassic volcanism was superimposed on the Triassic arc. In this case, if the calc-alkaline Mount Somers Volcanics are subduction-related, they may represent a change in subduction regime and the presence of a short-lived, more steeply dipping subduction zone around the end of the Early Cretaceous.

A very shallow-dipping subduction zone may favour the emplacement of the Esk Head Mélange by the mechanism presented in model 2. The downgoing slab would have delivered material to the "buttress" represented by the Rakaia subterrane at nearly 90° (similar to the scale model used by Cowan and Silling) and upward flow rather than underplating may have been promoted. If a dip of from 10 to 15° is postulated for the subduction zone, and the distance from the trench to the zone of upward flow is estimated as 50 km, then maximum burial of mélange material in the subduction zone ranges from roughly 9 to 13 km. This is compatible with the depth of burial suggested for elements of the Esk Head Mélange in chapter 4 - Metamorphism.

There are alternatives with regard to the timing of subduction. On one hand, subduction may have been initiated in the Jurassic, and continued at low rates until it accelerated to a climax in the Cretaceous. In this case, some of the volume of Early and Middle Jurassic sediments might be contained at some depth within the Pahau accretionary wedge (model 2), and some might have been uplifted during subduction and removed. Alternatively, a Jurassic plate boundary might have been dominated by transcurrent movement with a component of convergence, similar to the modern plate boundary on the South Island, and the onset of subduction might have been confined to the Cretaceous. In this case, Early and Middle Jurassic sediments would

have been largely removed during uplift in the Jurassic.

Uplift on the Pacific margin:

Sediments of the Pahau subterrane are strongly deformed and commonly achieve a steep dip similar to the Esk Head Mélange. In model 1, a phase of rotation has been postulated to account for the present steeply over-turned attitude of the mélange zone. Flattening noted in the mélange has been partly ascribed to this rotation event, but may be entirely an immediate post-mélange effect, directly related to mélange genesis (chapter 5). Compression and rotation of the entire accretionary prism containing the mélange zone would imply uplift and erosion throughout the Pahau subterrane.

In model 2, however, the Pahau is regarded as an active and continuously deforming margin, with maximum uplift on the landward margin and little uplift on the Pacific margin. The widespread occurrence of conglomerates in the Pahau (Andrews, 1980; Smale, 1978) reflects uplift on the landward margin. A relatively continuous stratigraphic sequence is described, however, in the late Early Cretaceous rocks of central Marlborough (Montague, 1981), suggesting little uplift in this area. This evidence accords most directly with the framework presented in model 2.

Accretion and emplacement of the mélange:

The progressive accretion of the Esk Head Mélange in a growing and landward-rotating accretionary prism, as postulated in model 1, might be expected to result in a series of "fanning" or imbricated planar fabrics across the zone and margins, notwithstanding the effects of later rotation. No systematic change in the dip of planar fabrics is observed, however, in traversing the mélange zone and margins.

The model does explain, however, the relatively consistent southwest facing directions noted within the *mélange* and margins.

On the other hand, in model 2, the consistently steep dip of the *mélange* zone and margins might be regarded as an initial consequence of the vertical style of emplacement, and little subsequent rotation need be invoked. It is uncertain, however, whether the consistent southwest facing of *mélange* elements would be preserved in such a regime of upward flow. "Early faults" and shear fractures which readjust the Esk Head *Mélange* may represent movement planes related to the episode of upward emplacement. Sinistral faulting and flexuring of the *mélange* zone remain post-emplacement effects, possibly related in some way to the cessation of subduction.

In summary, model 1 postulates genesis of the Esk Head *Mélange* in a shallow, westward-dipping subduction zone, accretion and subsequent landward tilting in a growing accretionary prism. Model 2 involves tectonic emplacement of the *mélange* as a steeply dipping zone on the landward margin of the accretionary prism by subduction-driven upward movement. Both models explain some aspects of the Esk Head *Mélange*, but model 2 accords more directly with regional geologic observations and is the preferred hypothesis of this study.

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APPENDIX I

POINT COUNTING PROCEDURES

Sandstone thin sections were stained with sodium cobaltinitrite and K-rhodizonate (using the method outlined in Lewis, 1981) to aid in the distinction of K feldspar, plagioclase and quartz. Four hundred points were counted in each section using a Swift automatic point counter. Theoretical reliability of compositional values obtained is within 5% of true values at the 95% confidence level (Van der Plas and Tobi, 1965).

Quartz or feldspar noted as a component of a larger grain (e.g. sedimentary or volcanic rock fragment) was counted as the host grain. Percentages represented by myrmekite/granophyre or perthite in any section are minor, and were not reapportioned in recalculating Q:F:R values. The problem of distinguishing matrix from flattened rock fragments, raised by Bradshaw (1972) and Andrews *et al.* (1976) was noted in several samples. Consistent efforts were made to identify flattened rock fragments.

APPENDIX II

PALEONTOLOGY

No new macrofossil localities were established in the course of this study. Attempts to recover microfossils were made with 1) cherts, 2) a tuffaceous limestone sample, and 3) siltstone and mudstone samples.

1) Cherts

Five chert samples were processed using the method outlined by Pessagno and Newport (1972), in an attempt to recover identifiable radiolaria. These were sample numbers 179, 180, 181, E-40 and E-56. Sample 181 displayed sparse recrystallized casts of radiolaria in thin section and was processed twice. No identifiable radiolaria were recovered from any samples. Samples examined in thin section have suffered extensive silica recrystallization and the survey undertaken suggests that cherts of the Esk Head/Okuku area may be, in general, too highly recrystallized to preserve radiolarian assemblages which can be dated.

2) Tuffaceous limestone (sample 195; M34/f151)

Tuffaceous limestone found in float at M34/596 924 (shown in figure 2.27) was examined in thin section and found to contain abundant volcanic rock fragments, recrystallized shell fragments, rounded echinoderm fragments and sparse foraminifera. Several portions of the sample were disaggregated using a very dilute solution of HCL and foraminifera recovered were mounted and submitted to Dr. C.P. Strong, N.Z. Geol. Survey, Wellington. Specimens were highly recrystallized and only a tentative identification of *Lituotaba* sp. and *Pseudonodosaria* sp. was possible (C.P. Strong, pers. comm., 1982). A ribbed shell structure suggestive of

Monotis was noted in casts of recrystallized shell material after dissolution. The sample is believed to be Warepan in age but fossil evidence is considered scanty.

3) Siltstone/mudstone samples

Six samples of siltstone/mudstone were processed using standard micropaleontological techniques in an attempt to recover datable palynomorphs. These were samples E-23, E-24, E-29, 136, 155 and 174. Samples were collected from siltstone/mudstone beds within bedded sandstone/mudstone sequences. Only two samples E-29 (L33/f4) and 174 (M34/f140) yielded any palynomorphs. Sample L33/f4 was collected from a bedded sandstone/mudstone sequence on the North Esk River at L33/451 204 and sample M34/f140 from a bedded siltstone in the South Branch Waipara River at M34/620 964.

Microfossil assemblages were submitted to Dr. J.I. Raine, N.Z. Geol. Survey, Wellington, for identification. Assemblages in the two samples are similar and a microfossil list is provided below. The presence of acritarchs indicates a marine environment of deposition (J.I. Raine, pers.comm., 1982). The systematics of New Zealand Mesozoic spores is not yet well established and a precise age determination of these samples is not possible. Dr. Raine does suggest, however, that both samples are "certainly not older and very unlikely to be younger than Jurassic". He tentatively suggested a Ururoan or Temaikan age.

Microfossil list

(J.I. Raine, 1982)

	<u>L33/f4</u>	<u>M34/f140</u>
Acritarcha:		
<i>Pterospermella</i> sp.	x	
<i>Veryhachium</i> sp.	x	
<i>Micrhystridium</i> sp(p).	x	x
<i>Cymatiosphaera</i> sp.		x
<i>Tasmanites</i> sp.		x
Bryophyta:		
<i>Foveosporites moretonensis</i> de Jersey	x	
Lycophyta:		
<i>Uvaesporites</i> sp.	x	x
<i>Anapiculatisporites dawsonensis</i> Reiser & Williams	x	
<i>Aratrisporites</i> sp.	x	
<i>Camarozonosporites rudis</i> (Leschik) Klaus	x	
<i>Staplinisporites</i> sp.	x	
<i>Neoraistrickia</i> sp.	x	x
Pterophyta:		
<i>Dictyophyllidites harrisii</i> Couper	x	x
<i>Duplexisporites problematicus</i> (Couper) Playford & Dettmann	x	x
<i>Polypodiisporites ipsviciensis</i> de Jersey	x	x
<i>Baculatisporites</i> cf. <i>comaumensis</i> Cookson	x	
' <i>Leptolepidites</i> ' sp.	x	
<i>Gleicheniidites senonicus</i> Ross		x
indet. granulate spores	x	x
Gymnosperms:		
<i>Alisporites australis</i> de Jersey	x	x
<i>Exesipollenites tumulus</i> Balme	x	?
<i>Ephedripites</i> cf. <i>steevesii</i> (Jansonius) de Jersey	x	
<i>Callialasporites segmentatus</i> (Balme) Srivastava	x	x
<i>Classopollis</i> sp.	x	x
<i>Vitreisporites pallidus</i> (Reissinger) Nilsson		x
indet. bisaccate pollen		x